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THE UNIVERSITY OF ALBERTA

INFORMATION PROCESSING AND HUMAN ABILITIES

by

Ⓒ JOHN ROBERT KIRBY

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled "Information processing and human abilities", submitted by John Robert Kirby in partial fulfilment of the requirements for the degree of Doctor of Philosophy.

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ABSTRACT

An alternative model of cognitive abilities has been proposed by Das and his colleagues (Das, Kirby & Jarman, 1975), based upon the clinical and neurophysiological work of Luria. According to this model, information is integrated in the brain in two ways: through simultaneous processing (in which a quasi-spatial grouping is formed), and through successive processing (in which a temporal grouping or series is formed). A battery of cognitive tests has been evolved that normally yields factors identifiable as simultaneous and successive processing, and a third, speed factor. The present study was designed to relate this model of cognitive abilities with three other cognitive models: the traditional Primary Mental Abilities (PMA) model, Paivio's model of imagery and verbal processes, and that of syntagmatic and paradigmatic language processing.

A total of 104 grade 4 boys from regular classrooms were tested. A principal components analysis was performed on the simultaneous-successive tests, and the resultant factor structure replicated previous results. The PMA battery was also factor analyzed, producing Reasoning, Spatial and Memory factors.

A variety of methods was employed to relate these two batteries of tests. The tests of both batteries were submitted to one principal components analysis, both batteries were related through Tucker's interbattery factor analysis, and factor scores for each battery were correlated with the factor scores for the other battery.

A number of patterns was seen to recur in the analysis. While

simultaneous processing was strongly related to spatial ability, it was no more related to inductive reasoning than to memory. Again, while successive processing was related to memory, this relationship was no stronger than that between simultaneous and memory . Successful performance on both concrete and abstract paired associates was related to simultaneous processing; successful paradigmatic and syntagmatic performance was similarly related to successive processing.

The results indicated that simultaneous processing, in addition to being important in spatial tasks, played a role in the coding or chunking that occurred in the various memory tasks. Coding was important in forming links between essentially unrelated words (the concrete and abstract paired associates) and when subjects were allowed a good deal of time to study the lists (the PMA memory tasks). The results confirmed that successive processing was involved in temporal associations between items; this was manifested in successive processing's role in the remembering of pairs of words that had high associative frequencies (syntagmatic and paradigmatic paired associates).

A general model was presented to describe in information processing terms the ways in which individual difference variables (e.g., abilities) arise. This cognitive model was intended as a composite of Luria's model of brain function, recent experimental work in cognition, and recent attempts to describe the cognitive systems that produce individual differences in intellectual tasks. While only in outline form, this model stresses the many determinants of individual differences, the importance of processes and plans, and the problems that are associated with process-oriented models.

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CHAPTER I

INTRODUCTION

Scientific psychology has evolved two methodologies for the study of human behavior (Cronbach, 1957). Experimental psychology has attempted to construct laws for the effects of environmental manipulations upon 'persons-in-general', while correlational or individual differences psychology has described the structure of individual variation in isolation from environmental effects. The major result of Cronbach's (1957) plea for the unification of these two disciplines has been the study of Aptitude x Treatment interactions, wherein the effects of environmental manipulations are modulated by individual difference variables. This methodological hybrid has generated extensive research, and though significant interactions have been elusive (Goldberg, 1972), the new discipline is flourishing (Cronbach, 1975).

More recently (Estes, 1974; Carroll, 1974), a second form of integration, logically derived from Cronbach's statement, has begun in the cognitive domain. The goal of this integration is the description of individual difference variables (abilities, intelligence) in terms of constructs now employed in experimental psychology. Briefly, it is hoped that the use of the cognitive, process-oriented constructs will aid in an understanding of the nature of intellectual ability.

This cognitive approach to individual differences, or psychometric variables, which seeks to understand the nature of covert processes that underlie behavior, in addition to predicting future behavior, is not novel. The history of psychometrics is replete with efforts to define the nature of, for instance, intelligence (e.g., Thorndike et al., 1921). These efforts have not been judged successful. Although mental tests originate in some conception of what mental ability must be, the trend in psychometrics has been away from a theory of intelligence and toward a science of prediction. As McClelland (1973) and others have noted, however, successful prediction, even at its present asymptotically high levels, does little to diagnose the causes of poor performance or to suggest means of improving that performance.

Why has a theory of intelligence been so difficult to construct? If one views a theory as a model which simulates some observed phenomena, the difficulties can be seen to have been not only in constructing the model which simulates, but in defining the phenomena to be simulated as well. Because the concept of intelligence is so global, definitions avoid vagueness ('intelligence is adaptive functioning') with difficulty. Alternatively, definitions which stress predictive validity ('intelligence is measured by whatever correlates with success in school') do little to unearth the mechanisms by which such correlations come about.

Rather than a broad construct of intelligence, current models of human ability stress a multifactorial conception of cognitive ability. As Jensen (1970) and Vandenberg (1968, 1973) have recognized, a major value of such a conception is in the rich provision for Aptitude x Treatment interactions. The practical importance of a multifactorial model of human ability will depend upon what these factors can predict, and whether quantitative and qualitative differences in abilities and ability patterns can be related to performance following certain treatments (e.g., educational programs) and in certain real life situations (e.g., job performance).

This fractionation of global intelligence also aids in theory construction. By categorizing the various kinds of intellectual performances, the multifactorial model of abilities allows the phenomena that are to be simulated to be seen in better detail. In this sense, the multifactorial model of intelligent behavior acts not so much as a theory of intelligence (i.e., that which explains or simulates the phenomena), but rather as a definition of intelligence (i.e., delineating that which is to be simulated).

At least three sources can be found for a theory of human cognitive ability. The first and most obvious is the field of psychometrics, which has traditionally studied human ability. A second source for a theory of intelligence is cognitive experimental psychology. In attempting to describe learning and performance, experimental psychology has given birth to a large number of covert processes and structures (e.g., rehearsal, short-term memory, associations) which are inferred to underlie behavior. These processes and structures are to be the components of the model that is to simulate the phenomena defined by the psychometricians. The third source, physiological psychology, acts as a cautionary agent. What knowledge we do have of the neurophysiology of the brain can suggest tentative psychological hypotheses but also serves to render others improbable.

The present study should be seen as the beginning of the construction of a theory of human cognitive ability. It will attempt this by relating traditional mental abilities (the Primary Mental Abilities) and some concepts that emerge from experimental psychology (imagery and verbal processes, paradigmatic and syntagmatic language processing), with a model of cognition recently developed by Das and his colleagues (Das, 1972, 1973a, 1973b; Das, Kirby & Jarman, 1975). This model, that of simultaneous and successive processing, has its roots in the neuropsychological work of Luria (1966a, 1966b, 1973a) with the brain-damaged. In its use of process concepts similar to those of experimental psychology, it is typical of recent attempts (Carroll, 1974; Estes, 1974; Messick, 1972, 1973) to so describe cognitive ability.

The present study employs a number of conceptions of cognitive ability, and a comparison of these will form a basis for the integration of the many models of cognition that exist. The use of cognitive constructs that have proved helpful in experimental psychology should suggest directions for future theory to take. Furthermore, in that the simultaneous-successive model is relatively new, the nature of its relationships with other models will help to clarify the nature of this model itself.

CHAPTER II

REVIEW OF LITERATURE

Three sources have been identified for a theory of intelligence: psychometric theories of abilities, cognitive models in experimental psychology, and physiological psychology. Each of these areas will be reviewed and the simultaneous-successive processing model will be described.

The first section will present a brief history of the changing models of psychometric abilities. This review will attempt to develop a current picture of the major abilities, which will later be related to information processing constructs. Subsequent sections will identify those information processing constructs, and will summarize what contributions physiological psychology can make to an information processing model of abilities.

Psychometric Theories of Abilities

The study of psychometrics can be traced back to Sir Francis Galton in the late 19th Century. His efforts to study mental ability in an evolutionary perspective and to develop tests of general mental ability were a stimulus for the testing movements in Britain and in the United States. At various times, Charles Spearman, Cyril Burt and J. M. Cattell (who was to have E. L. Thorndike as a pupil) worked under Galton.

Galton favored the idea of a single, general intellectual ability that was based upon the fineness with which the individual could make sensory discriminations. Galton's immediate successor was Spearman (1904, 1923, 1927), who supported the concept of general ability and developed the theory of Two Factors: any cognitive operation is served by the general factor (g) which all cognitive operations have in common, and by a specific factor (s) which is peculiar to that cognitive operation. The general factor was conceived of as an energy or power which served the whole nervous system, and which could be concentrated upon a specific group of neurons, the specific factor which was the 'engine' that actually accomplished the cognitive operation. Cognitive operations (noesis) were of three kinds: apprehension of experience, eduction of relations and eduction of correlates.

In France, Binet accepted the idea of a general ability, but saw it rather as the result of a number of operations (at first attention, memory and judgment, but later goal setting, comprehension, solution finding and self-criticism). These individual operations would have to be sampled to obtain an index of general ability.

In America, Terman adopted Binet's tests, but misinterpreted him (according to Guilford, 1973) to mean that there was one general ability that operated in a number of ways. That one general ability was 'intelligence', to which a single mental-age score could be given.

Though they disagreed about the nature of that one general ability, Galton, Spearman, Binet and Terman agreed that one general factor could account for the positive correlations that existed among cognitive tests. Galton's one-time assistant, J. M. Cattell, did not obtain such high correlations, and his student Thorndike began to develop a radically different view. To Thorndike, intelligence was the aggregation of a set of independent specific habits or skills. When tests did correlate, it was only because the skills sampled overlapped. Similar views were held by Thomson and by Thurstone.

In 1927, Spearman classified the one-factor theories of Terman and Binet as 'monarchic', Thorndike's independent abilities as 'anarchic', old faculty psychology as 'oligarchic', and his own Two Factor theory as 'eclectic' because it salvaged all that was of value in the other theories. Another psychologist who had worked with Galton, Cyril Burt, was a major proponent of a class of models of intellect which could be called hierarchical. He and Vernon accepted Spearman's general factor, but gave great importance to group factors, which were intermediate in specificity between the general and specific factors. Vernon's (1950) hierarchical structure of human abilities gained rapid prominence as the successor to Spearman's; under g it proposed two major group factors, one verbal-educational (v:ed) and one practical-spatial-mechanical (k:m). Further analysis of v:ed tests would result in verbal, numerical and other school-related factors, while further analysis of k:m tests would produce more specific factors in the domain of spatial ability, psychomotor skills and mechanical knowledge.

Vernon's major competitor was Thurstone and his 'anarchic' Primary Mental Abilities (Thurstone, 1938). However, structure could be applied to these 'independent' abilities through hierarchical factor analysis: the primary factors were allowed to correlate, and thus could be analyzed to produce higher-order factors. These higher-order factors were interpreted as being very similar to those found by Vernon, in spite of totally different factor analytic techniques. In this way, the monarchic, anarchic and eclectic models that Spearman described could be united into an hierarchical model of abilities.

The most recent versions of Thurstone's primary mental abilities model are those of French, Ekstrom and Price (1963), and of R. B. Cattell and Horn (Cattell, 1963, 1971; Horn & Cattell, 1966) and are hierarchical. Although there were great theoretical differences between the model of Vernon and that of Cattell and Horn, a consensus was emerging. That consensus supported an hierarchical model of abilities, with two major groupings of factors, one verbal and educational and the other nonverbal, spatial, and less related to schooling. The remainder of this section will examine that hierarchy of abilities, and following Horn (1975), suggest a more comprehensive list of psychometric higher-order factors.

Verbal and nonverbal intelligence

The factors which Cattell and Horn see at the top of the hierarchy, in place of Vernon's v:ed and k:m, are fluid and crystallized intelligence, which play important roles in Cattell's complex theory of abilities (Cattell, 1971). General fluid intelligence (Gf) is hypothesized to be an innate, biologically determined potential, and can only be measured if the effects of experience, and especially school, are minimized. The largely nonverbal tests of Gf, which require adaptation to new situations in which earlier learning has little impact, are thus proposed as culture-free. While different in definition from Vernon's k:m, Gf shares with k:m a number of lower-order spatial and perceptual abilities. In fact, it will be shown that Cattell's Gf is more similar to Vernon's recently proposed i (induction) factor. As will be discussed below, Jensen (1973) sees both Gf and Gc as aspects of his Level II ability, or general intelligence.

Through the course of experience and mental development, Cattell sees the fluid intelligence being invested or crystallized in specific learning experiences, which gives rise to a general crystallized ability (Gc). This factor is more similar to Vernon's v:ed, being in our culture largely the result of school experiences. It can be measured with school- or achievement-oriented tests.

The two models can be loosely said to propose an hierarchical structure of abilities, with two major groupings of factors, one verbal and the other spatial-perceptual, or nonverbal. This bipartite division of abilities is largely responsible for the 'verbal-performance' or 'verbal-nonverbal' separation seen in popular IQ tests such as the Wechsler Intelligence Scale for Children, or the Lorge-Thorndike. In more recent publications, Horn and Cattell (1966) and Vernon (1969) have suggested the existence of other higher-order factors such as general visualization, general memory, general verbal fluency, and general speediness.

Spatial/field independence

Further research, some of it in areas far removed from traditional abilities surveys, has resulted in a greater complexity of higher-order factors. Witkin (1967; Witkin & Berry, 1975) has presented a theory of psychological differentiation, which relies upon the concept of field independence. As the organism develops, its psychological systems become more differentiated or separate, and the organism becomes more able to perceive units as articulated or separate. In the perceptual-cognitive domain, this differentiation is manifested in the increased ability to separate parts of a perceptual field from the field as a whole, that is, field independence. Field independence is conceived of as a cognitive style, and is measured by tests such as the Tilting-Room-and-Chair, the Rod-and-Frame, and the Embedded-Figures Tests.

While Witkin and Berry (1975, pp. 74-75) protest the identification of field independence with other cognitive dimensions, Horn (1975) and MacArthur (1975) have presented evidence suggesting that it is related to what has traditionally been called spatial ability. MacArthur (1973, 1975) has shown the Embedded Figures Test to load highly on a factor also defined by the WISC Block Design and the Human Figure Drawing tests in a variety of groups. Vernon (1972) finds the Embedded Figures Test loading with tests of Flexibility of Closure. While Witkin argues conversely that tests such as Block Design and Human Figure Drawing are measures of field independence, Vernon (1972) and Horn (1975) suggest that the Embedded Figures Test in particular can be subsumed under a broad factor which Horn calls general visualization (Gv). This factor, which also embraces the Spatial, Flexibility of Closure, Speed of Closure, and Visualization primaries, is essentially higher-order spatial ability. It is separate from both of the previous general factors, Gf and Gc (Vernon, 1972; MacArthur, 1973, 1975). Vernon also suggests that the other measures of field independence (Rod-and-Frame, Tilting-Room-and-Chair) involve a separate, visuokinetic function.

At this point, then, previous work suggests the existence of three general cognitive factors: The first is called Gf by Horn and Cattell, i (for induction) by Vernon, and inductive-reasoning-from-nonverbal-stimuli by MacArthur. The second is called Gc by Horn and Cattell, and v:ed (or verbal-educational) by Vernon and MacArthur. The third is called Gv by Horn, k:m (for spatial-perceptual-practical) by Vernon, field independence by Witkin, and spatial/field-independence by MacArthur.

Memory

In the context of an extensive theory of mental abilities and social class differences in achievement, Jensen (1969, 1970, 1973, 1974) has stressed the importance of memory as an ability. His theory proposes two categories of abilities, Level I (associative memory) and Level II (conceptual learning and problem solving), which differ in the amount of abstractness or complexity involved. The complexity of a task is indicated by the amount of stimulus transformation and manipulation required.

Jensen perceives his Level I-Level II distinction as complementing rather than competing with Cattell's Gf-Gc distinction. In theory, he states (1970, pp. 157-158), the two distinctions are orthogonal. In practice, however, he has found a Level I Memory factor to emerge separate from Level II Gf and Level II Gc factors, in three different ethnic groups (Jensen, 1973).

Horn (1975) and Hakstian and Cattell (1974) suggest that a broad (general) Memory factor can be found, separate from Gf, Gc and Gv, when enough different memory variables are considered. The tests which combine to define this broad memory factor share the characteristic of Jensen's Level I abilities: minimal transformation of stimulus input is required for a correct response.

The inclusion of a Memory factor in the roster of broad ability factors is also indicated by the importance that Jensen attaches to it in describing group differences, Aptitude x Treatment interactions and possible remedial strategies. He believes that, in certain tasks, groups or individuals who have low Level II ability can be instructed to employ strategies which rely upon Level I rather than Level II ability.

Verbal productive thinking and general speediness

Two more general cognitive factors can be added to the four identified above, though with less certainty. Reviewing the literature on 'creativity' or divergent thinking, Horn (1975) concludes that there is a relatively well-defined cluster of tests which he labels Verbal Productive Thinking. These tests require a facility in listing multiple uses or similarities of objects, or in writing multiple interpretations of what simple line figures mean. While this factor has been shown to stand apart from, though correlated with, measures of intelligence, there is as yet no compelling evidence that it represents creativity. It is best thought of as a verbal fluency factor.

A sixth general factor was referred to as general speediness (Gs) by Horn and Cattell (1966) though it is omitted in Horn's later review (1975). It is defined by tests which themselves are very simple (writing, printing, adding, cancelling) but are timed and require rapid responding.

The growth of abilities

A final issue with regard to psychometric theories of abilities which should be mentioned, but which cannot be covered in depth, concerns the development of those abilities. Again a consensus is emerging from a variety of sources, and it is important because it relates to the question of what abilities actually are.

The foundations for this consensus were laid by Thorndike in the early 20th Century with his proposals that learning came about through the establishment of neuronal connections between stimuli and responses in the brain, and that intelligence was indexed by the number of those connections. Hebb (1949), Piaget (e.g., 1950) and Gagné (e.g., 1968) have suggested developmental models in which these lower-order units (be they thought of as S-R connections or as more complex representations of the external world) are integrated into higher-order cell assemblies or schemata as a result of the organism's interaction with the environment. These higher-order cognitive structures are equivalent to abilities; their generality is a function of the variety of performances in which they are involved. Thus, abilities are seen to develop as a cumulative integration of cognitive schemata.

The pattern of abilities that develops is a function of innate predispositions within the organism, but also dependent upon the pattern of cognitive experience. Thus, as Ferguson (1954, 1956) stated, groups which value different performances, or which learn different tasks, or which are taught to perform the same task in different ways, can be expected to develop different abilities and different patterns of abilities. Ferguson also added the concept of transfer: existing cognitive structures (abilities) are applied to new learning situations, their success being a function of the quality of those structures and the similarity of the new situation to those from which that structure developed. Such a model is gaining increasing support (Buss, 1973a, 1973b) and is particularly relevant in cross-cultural studies of ability patterns (Cole, Gay, Glick & Sharp, 1971; Scribner & Cole, 1973; MacArthur, 1973, 1975). It is also important as a limit upon the generality of the factor patterns described above, most of which were derived from studies of white English or North American individuals. Different factors might well emerge in different groups, and cognitive performances might be differently valued.

Summary

Some prominent psychometric approaches to identifying the abilities of man have been reviewed in the preceding sections. Two essentially insoluble problems exist with the factor analytic approach to abilities. These are the number (and type) of variables to include, and the level at which the analysis is to stop. The careful factor analyst can design his variable set in such a way as to insure that certain factors will emerge, or that they will not. For example, if one includes relatively few memory tests (e.g., Thurstone, 1938), a first order memory factor may well emerge, but this will likely disappear in higher-order analyses. On the other hand, by including a number of memory tests (e.g., Kelley, 1964), a number of primary memory factors will surface, and they can be predicted to cluster as a higher-order factor. From this it can be seen that the presence or absence of higher-order factors (e.g., Verbal Production Thinking, general visualization), as well as lower-order factors, is more a function of test selection than psychological reality.

While the nature of the factors extracted is a function of the nature of the variables input, the number of factors depends upon how long the analysis continues. If one samples cognitive behavior well and is content to stop with first-order factors, a relatively large number of relatively specific factors will be obtained. Conversely, engaging in higher-order analyses will produce fewer and broader factors as a mathematical certainty.

Within these limitations, however, some regularities can be observed in psychometric theories of abilities. These theories taken as a group suggest the existence of six broad cognitive factors: Gf, Gc, Gv, Memory, Verbal Productive Thinking, and Gs.

Information Processing and Human Abilities

Cronbach (1957) described scientific psychology as being separated into two disciplines: experimental psychology and the psychology of individual differences. That separation has insulated the study of human abilities (individual difference variables) from advances made in experimental psychology, and vice versa. Extensive theories (as evidenced by the preceding section) of human behavior were developed upon the basis of individual differences and minimal manipulation of independent variables, while perhaps even more massive theories of human behavior were constructed from the manipulation of laboratory variables and the treatment of individual differences as 'error'.

It is now apparent that a rapprochement is under way. Cronbach (1975) reports that the study of Aptitude x Treatment interactions is flourishing. Even as distinguished an experimentalist as Underwood (1975) has come to the realization that not only are individual differences relevant to experimental psychology, but also that they may provide a 'crucible' for theory construction, a critical test for the accuracy of theories. Carroll (1974) and Estes (1974) have both attempted interpretations of psychometric tests in terms more familiar to the experimental psychologist (e.g., short-term memory, chunking, retrieval).

The indications are numerous that the split is ending.

Before the split can be effectively closed, however, a fuller understanding of its nature is necessary. There are other fundamental differences between the two disciplines besides their treatment of individual variation and their desire to manipulate independent variables. The development of concepts and theories has followed a different historical course in the two disciplines.

After Watson's (1913) Behaviorist manifesto, experimental psychology's development was overwhelmingly behavioral and empirical. Emphasis was placed upon observables, not on what was actually happening 'inside the head'. Theories dealing with 'mental images' were branded as non-scientific and discarded. Particularly in North America, the study of cognition, and the construction of theories which used cognitive terms, were left to the psychometricians or differential psychologists. Thus, as Carroll (1974) points out, early leading figures in psychometrics such as Spearman (1923, 1927) and Thurstone (1938) were concerned with the nature of intelligence. They interpreted their factors as ultra-spective concepts (Coan, 1964), hypothetical constructs having reality beyond the data from which they were inferred.

Theoretical development occurred differently in either field in subsequent years. In differential psychology, the trend was away from the cognitive, toward the empirical. Intelligence tests were said to measure 'what intelligence tests measure'. Writers such as Anastasi (1938) and Burt (1940, 1949) accused Thurstone and others of resurrecting 19th Century faculty psychology, and preferred the designation of factors as 'principles of classification'. Until recently, psychometrics had become increasingly empirical, in proportion to the increasing distaste for 'psychological entitles', 'faculties', and 'mental engines'.

Experimental psychology in the same period has pursued a parallel but opposite course. After many attempts at purely associative, empirical theories (Hull, 1943; Spence, 1956), cognitive constructs returned to experimental psychology. Theoreticians (Hebb, 1960; Miller, Galanter & Pribram, 1960) saw that psychology had developed a selective inattention to problems either mental or complex. Experimenters, some of whom shunned the construction of broad comprehensive theories and concentrated on the narrower aspects of conditioning or memory, were unable to prevent the intrusion of cognitive constructs such as 'cognitive maps', 'images' and 'covert rehearsal' in their models (e.g., Tolman, 1948; Neisser, 1967). Particularly in the area of memory (Jenkins, 1974), experimental psychology has embraced cognitive constructs and to a large extent has become the study of human 'information processing' (Estes, 1975, p. 2), which by definition concentrates on what happens 'inside the head', between input and output.

If the two disciplines of scientific psychology are to be united, they must at least interpret their models in the terms of each other's metatheory. In effect, that requires a common metatheory. The strictly behavioral or empirical model has been found to be inadequate to describe the phenomena (e.g., Neisser, 1967; Miller, Galanter & Pribram, 1960) and can even be accused of ignoring the true subject matter of psychology (Hebb, 1974). The metatheoretical viewpoint that has been adopted as the basis of the reunification has been the cognitive. The resultant models have been ones which describe information processing.

Information processing in a psychometric context

Messick (1972, 1973) has been a major instigator of attempts to go beyond the structural or taxonomic classification of factors towards a functional model of psychological process. Echoing Royce (1963), he notes that factor analysis can establish important variables or concepts, but cannot easily link them in functional relationships. According to Messick, complex cognitive behavior (learning, problem solving, and creativity) must be understood as a result of a sequence of component processes, whose nature and interrelationships factor analysis is unlikely to reveal.

Those component processes have long been studied in experimental psychology, to whose methods they are more amenable. They are parts of the traditional memory models (e.g., Atkinson & Schiffrin, 1968; Hunt, 1971) and include short-term memory (STM), intermediate-term memory (ITM), long-term memory (LTM), and various executive or control processes. Whether these components, especially the various memories or 'stores', should be considered as structures or processes, is a question left to future research and thought. The point is that they are cognitive terms which can be functionally linked.

Hunt (Hunt, Frost & Lunneborg, 1973; Hunt, Lunneborg & Lewis, 1975; Hunt & Lansman, 1975) has investigated the characteristics of individuals who are high and low in verbal (VA) and quantitative ability (QA), in terms of his Distributed Memory Model (Hunt, 1971, 1973). He finds consistent relationships between the psychometric (VA and QA) variables and performance in a variety of experimental tasks: high VA is related to rapidity of STM processes, while high QA is related to resistence to interference. Carroll (1974) has subjectively analyzed 48 of the French, Ekstrom and Price (1963) tests, with regard to which components of Hunt's model would produce individual differences in the tests. Of the 24 cognitive factors measured by these tests, he found eight to be related to STM, one to ITM, and 15 to LTM. He also found the factors to differ in terms of three types of operations: attentional processes addressing sensory buffers, processes addressing ITM or LTM, and executive processes. For example, he characterizes the tests of Spatial ability as requiring mental rotation (executive process) of STM contents; associative Memory involves the addressing of ITM contents and STM rehearsal; and Inductive Reasoning requires the addressing of LTM contents for relevant logical hypotheses.

Estes (1974) analyzed several WAIS and Stanford-Binet subtests in a manner similar to Carroll's. Like Carroll, he concludes that individual differences in tests as simple as Digit Span or Vocabulary could arise for a variety of reasons related to cognitive processing. For example, failure to define a word correctly could be due to the lack of the necessary memory structure, the lack of retrieval cues, the low availability of words to use in the definition, or a failure to understand what is required in the task.

These attempts to describe psychometric abilities as a sequence of cognitive processes are not necessarily directed toward developing new tests of 'intelligence'. As McClelland (1973) has said, intelligence and aptitude tests were designed to predict specific performances (e.g., school grades) and they do this well. Predictive validity, these theorists feel, is not enough. Efforts should be made to understand the nature of intelligence, the nature of the cognitive processes which are required for adaptive functioning. In this way, with some understanding of "what brings about specific kinds of competence and incompetence in intellectual activity . . . the primary purpose of intelligence testing [will] become that . . . of indicating and guiding measures that can be taken to improve intellectual performance (Estes, 1974, p. 749)". Benefits should accrue not only for the education of children, but also for a theory of intelligence.

Imagery and verbal processes

Paivio (1971, 1975) has recently elaborated his dual coding model of associative memory (1969) to encompass cognition in general. He distinguishes between two modes of thought or information processing, the imaginal and the verbal. The imagery system is specialized for the processing of nonverbal information stored in the form of images or analog representations of concrete things. The imagery system is also specialized for "synchronous organization and parallel processing (Paivio, 1975, p. 148)".

The verbal system is specialized for the processing of abstract linguistic units which are discrete and sequentially arranged; these units are only arbitrarily related to things, according to the conventions of some language. In contrast to the imagery system, the verbal system engages in sequential organization and serial processing.

Paivio's model has been criticized for the nature of the constructs (imagery and verbal systems) that he posits (Pylyshyn, 1973; Kirby & Das, 1976), and for the manner in which he assigns modes of processing for these systems (Nelson, Brooks & Borden, 1973; Snodgrass & Antone, 1974;

Bugelski, 1974; Kirby & Das, 1976). Constructs such as imagery and verbal systems, and the image itself are of questionable explanatory use (Pylyshyn, 1973), and are difficult to see as having any neurophysiological reality. As Pylyshyn suggests, they are in need of further reduction. However, Paivio's assignment of processing modes (parallel and serial) to these mediation systems is not an adequate solution: in addition to being post hoc, it is incorrect (Nelson, Brooks & Borden, 1973; Snodgrass & Antone, 1974; Bugelski, 1974).

An additional difficulty is in relating Paivio's two cognitive systems to the psychometric research discussed previously. In a number of studies he and Ernest (Paivio & Ernest, 1971; Ernest & Paivio, 1969, 1971a, 1971b) have equated imagery ability with performance on spatial tests. If such is the case, and if Paivio (1971) is correct that latency to form an image is an index of imaging, then it is not easily understandable why spatial ability is equally correlated with latency of evoking an image or a verbal associate for either concrete or abstract words (Ernest & Paivio, 1971a). In the same way it is difficult to relate his 'verbal' system to an ability factor: it is correlated with spatial ability; in definition it resembles verbal or crystallized ability; and the tests which Paivio uses to measure it (abstract paired associates) should be expected to load on a memory factor.

Paivio's attempts at building a theory of cognition have not been as comprehensive and thorough as those of others, but they have been extensive in the domains of perception and memory. In that it represents a concerted effort towards an information processing model, Paivio's theory merits comparison with other models of cognition.

Syntagmatic and paradigmatic language processing

Another approach to a model of cognition was begun when Jenkins (1954) introduced a distinction between two types of word association, syntagmatic and paradigmatic. A syntagmatic association is one between words which have some kind of sequential relationship to each other and are generally members of different grammatical classes forming a syntactically organized phrase, sentence or sentence fragment. Thus throw and ball are syntagmatically related. A paradigmatic association, on the other hand, is one between words of the same grammatical word class, and which are semantically substitutable (can replace each other in sentences). Thus throw and toss, and cold and warm are related paradigmatically.

It has been shown since that the syntagmatic-paradigmatic distinction is related ontologically to development which takes place during childhood. In free association (Brown & Berko, 1960; Ervin, 1961; McNeill, 1963; Routh & Tweney, 1972), and in free recall clustering (Denney, 1974a; Denney & Ziobrowski, 1972), a tendency to categorize syntagmatically changes to a tendency to categorize paradigmatically. The shift takes place between the ages of 6 and 9 (Denney, 1974a). The paradigmatic categorization tendency continues through college and middle age (Denney & Ziobrowski, 1972), to old age, when a shift back towards a syntagmatic tendency takes place (Denney, 1974b, 1974c). In her research, Denney prefers the terms similarity and complementary for paradigmatic and syntagmatic, respectively, and has found evidence for the shift in categorization in studies of free classification, word definition, and conceptual styles as well (Denney, 1974a).

While there is still no satisfactory explanation of the syntagmatic-paradigmatic shift (Routh & Tweney, 1972; Denney, 1974a), there is evidence that increased paradigmatic clustering or classifying can be trained (Denney & Acito, 1974; see also, however, Routh & Tweney, 1972). Furthermore, it has been shown cross-culturally that increased Western schooling results in more paradigmatic categorization behavior (Cole, Gay, Glick & Sharp, 1971; Cole & Bruner, 1971; Scribner & Cole, 1973; Denney, 1974a).

The terms syntagmatic and paradigmatic have also been used as a classification scheme for various kinds of aphasic disorders (Jakobson, 1964). Furthermore, Pribram (1971, pp. 357-360) and Luria (1973b) have expanded upon Jakobson's scheme, and related it to Luria's (1966a, 1966b, 1973a) model of simultaneous and successive processing, which will be described in a later section.

The syntagmatic-paradigmatic developmental shift model was not intended as a theory of cognition, but relations can be seen between it and those theories discussed previously. Paradigmatic tasks require a degree of abstraction and relating that may be similar to that required for Inductive Reasoning. To the extent that the paradigmatic relations are of a visual nature, they may also involve the general visualization or spatial ability. Syntagmatic tasks are more difficult to classify; in that they require the maintenance of temporal order they may require memory ability, but to the extent that they tap functional relationships they defy classification.

Summary

'Information processing' is at best a vague term. In and of itself, it does not represent a solution to, or an adequate representation of, anything. Information processing theories are best thought of as a subclass of cognitive theories, all of which share a concern for postulating unobservable constructs whose interaction produces observable behavior. Calling the theory information processing rather than cognitive indicates the choice of a metaphor, a metaphor which is increasingly common in cognitive theories.

The information processing metaphor is a convenient language for discussing input, storage, retrieval and output of information. Theories that adopt this metaphor accordingly tend to postulate constructs which refer to these processes, which could be loosely classified as memory processes.

Three kinds of information processing approaches, neither exclusive nor exhaustive, were considered. Each represents in some way an attempt to characterize human cognitive behavior. Carroll, Estes, Hunt and Messick have begun the description of psychometric dimensions in cognitive terms, and the breadth of the psychometric variables makes their task, if not their solutions, comprehensive. Paivio has attempted to construct a theory of cognitive functioning on the basis of performance in relatively simple tasks; his imagery theory has become widespread even if inaccurate. Some recent research has concentrated on two different types of relations between words or concepts (syntagmatic and paradigmatic, which can also be thought of as modes of processing), and Denney has begun the task of relating this distinction to other cognitive variables.

Information Processing and the Brain

Simon (1972) has suggested that while cognitive psychology is not capable of the detailed neuroanatomical hypotheses of physiological psychology, it should at least attempt to produce hypotheses which are consistent with the knowledge that exists of the nervous system. This task is becoming easier because the physiologists themselves are talking in information processing terms (Pribram, 1971). In this section, Luria's model of simultaneous and successive syntheses will be presented, along with some extrapolations that have been made into the linguistic field by Luria and Pribram. Finally, some paradoxical results from the study of laterality differences in the brain will be briefly mentioned.

Simultaneous and successive syntheses

Luria (1966a, 1966b, 1969, 1973a) has proposed a model which divides the human brain into three functional systems or blocks. The first block consists of the upper brain stem, the reticular formation and the oldest parts of the limbic cortex and the hippocampus. It is responsible for maintaining wakefulness and arousal. The second block of the brain includes the posterior cortex (parietal, occipital and fronto-temporal lobes) and the underlying structures. It is responsible for the input, recoding and storage of information and is organized hierarchically. Deeper tertiary (or overlapping) zones synthesize information from primary (modality-specific) zones. The two modes of processing in which this block engages, simultaneous and successive processing, will be examined below. The third block of the brain consists of the anterior portions of the brain, the prefrontal lobes, which are evolutionarily the newest parts of man's brain. This block is responsible for the construction and execution of plans or programs. Through extensive connections with the other two blocks, it regulates and controls purposeful conscious action.

Luria's conclusion that the second block of the brain integrates or processes information by means of simultaneous and successive syntheses is based upon the examination of neurological patients suffering from gross brain damage to various parts of the left hemisphere. These syntheses can take place at the perceptual, memory and complex intellectual levels of functioning.

Simultaneous processing involves the synthesis of separate elements into groups that generally have spatial overtones, all portions of the synthesis being surveyable or accessible without dependence upon their position within the synthesis. This type of processing is required, for instance, in the formation of any holistic gestalt, or in the discovery of the relationships among two or more objects.

Simultaneous processing is impaired when the parietal-occipital regions of the brain are damaged. While the patient generally remains conscious and aware and retains narrative speech, he does exhibit deficits in certain kinds of tasks. Depending upon the depth and exact location of the lesion, the following may be impaired: understanding of logico-grammatical speech (e.g., who is your father's brother?), spatial orientation (confusing east and west), and executing spatial instructions (when told to 'draw a square above a circle', the patient draws a square and then a circle, in no particular relationship).

Successive processing involves the integration of separate elements into groups whose essential nature is temporal. Portions of this synthesis are accessible only in the temporal order of the series--each element leads to only one other, and access to any element is dependent upon the preceding elements. Successive processing is necessary for the formation or production of any ordered series of events.

Disturbances of successive processing result from damage to the fronto-temporal regions of the brain. Again depending upon the depth and location of the lesion, the following may be impaired: smooth serial actions (either perseveration takes place or order of actions is disrupted), retention and reproduction of rhythm and melody, and serial recall (though as many as 10 items can be recalled, the patient cannot learn to correctly order them). The patient retains conscious awareness, but finds that he must make a voluntary effort to perform simple serial movements; these movements have become de-automatized.

Luria's evidence for these processing factors comes from a technique which he calls syndrome analysis (Luria, 1973a), and which in function is remarkably similar to several multivariate analysis techniques. Brain-damaged patients are presented with a variety of tasks and meaningful relationships are sought between the location of the damage and the nature of the deficiency exhibited. These relationships are interpreted much as factors, discriminant functions, and canonical variates are.

Pribram (1971) has extended Jakobson's (1964, 1971) classification of aphasias (disturbances of receptive or expressive speech) and related it to Luria's work. Briefly, while aphasias can be classified as either expressive (Broca's) or receptive (Wernicke's), they can also be classified as disturbances of either simultaneous or successive processing. These classifications overlap, but are not isomorphic.

Several points should be made with reference to Luria's model. Luria's work has been with brain-damaged patients, and in most cases that damage has been to the left hemisphere. Accordingly, there may be difficulties in generalizing his model to normal, intact persons. The role of the right hemisphere in cognition is also left in doubt. However, since he has concentrated on verbal disorders, it is difficult to characterize the two sorts of disturbances he notices as other than processing disturbances.

One final source of confusion should be noted. The successive processing areas of the brain (fronto-temporal regions) are adjacent to the third block of the brain, where plans are constructed and controlled. By their nature, plans are sequential: they are designs for series of actions. It is possible, therefore, as Luria (e.g., 1973b) sometimes does, to classify the cortex not as block two and block three, but as posterior (temporal, parietal and occipital lobes) and anterior (premotor, prefrontal and frontal areas). The difference is in the group in which the successive areas of block two are located. While either distinction is feasible, the former (simultaneous and successive, both in block two) will be used here. The third block is separate from the two modes of processing and dependent upon both of them.

Laterality differences

The issue is further confused when one considers work done on the differences between cerebral hemispheres. Whereas Luria and the Soviets have concentrated on the left hemisphere, a series of Western investigators led by Sperry and Milner have concentrated on the difference between hemispheres.

Ever since the early observations of Broca (1888) there has been evidence accumulating that the two hemispheres in man do not perform equivalent functions, as they do in lower animals. Evidence has been gathered from three types of subjects: those with localized brain damage, those who have had the connections between hemispheres severed (split brain), and normals. This research is generally based upon observations of right-handed subjects, in whom lateral asymmetry is most clearly evidenced (Milner, Branch & Rasmussen, 1964).

The clearest hemispheric asymmetries of function are demonstrated with patients who have had a substantial portion of either cerebral hemisphere, or the entire hemisphere, damaged or removed. Damage to or removal of the left hemisphere impairs the learning and retention of verbal material, regardless of input modality or response type (recall or recognition) (Milner, 1971; Mountcastle, 1962). Ability to learn and retain auditory and visuospatial patterns which are not easily verbalizable (e.g., faces or melodies) is not affected. Conversely, damage to or removal of the right hemisphere impairs those functions described above as not impaired by left hemispheric damage (Kimura, 1963; Milner, 1971; Mountcastle, 1962). Again, the deficiency is independent of sensory modality or whether the response is by recall or recognition.

Learning and retention of verbal material is not affected.

Epileptic patients who have had the corpus callosum, which is the major nerve bundle connecting the two cerebral hemispheres, surgically severed are a second source of evidence regarding hemispheric asymmetries of function. The data from these split-brain patients also describe the left hemisphere ('by itself') as being more adept at essentially verbal tasks and the right at nonverbal tasks (Sperry, 1968; Sperry & Gazzaniga, 1967; Milner, 1971; Nebes, 1974; Gazzaniga & Sperry, 1967).

Much of the same pattern of results is found with normal subjects (White, 1969). Single letters, outline drawings of easily named objects, and digits are all identified or reacted to more accurately or more quickly when presented to the left hemisphere (Kimura, 1966; Wyke & Ettlinger, 1961; Geffen, Bradshaw & Wallace, 1971). On the other hand, it has been shown that dot ennumeration, dot localization, discrimination of line slopes, and recognition of faces are performed more efficiently by the right hemisphere (Kimura, 1966, 1969; Durnford & Kimura, 1971; Geffen _et al_., 1971).

While early investigators interpreted these results as meaning that the left hemisphere processed verbal input and the right hemisphere nonverbal, more recent researchers (Cohen, 1973; Nebes, 1974; Semmes, 1968) have instead begun to propose what can best be termed a processing distinction. Nebes' conclusions are that "the type of information processing required to solve the problem" determines which hemisphere is dominant for a particular task, that the left hemisphere "sequentially analyzes input, abstracting out the relevant details to which it associates verbal symbols", and that the right hemisphere "is seen to organize and treat data in terms of complex wholes, being in effect a synthesizer with a predisposition for viewing the total rather than the parts (Nebes, 1974, pp. 12-13). In other words, then, the difference between hemispheres is not in the nature of the stimuli which they process, but rather in the way in which they process (encode) those stimuli.

Nebes' reference to sequential and wholistic processing, and Cohen's (1973) explicit use of the terms serial and parallel processing are reminiscent of Luria's successive and simultaneous processing, respectively. While at one level of analysis it can be seen that the essence of simultaneous processing is parallel processing, etc., the relationship between the two models is much more complex. While the left hemisphere may engage primarily in sequential processing, it is implicitly verbal (as successive processing is not) because the speech musculature is controlled in the left hemisphere. Similarly, simultaneous (parallel) processing has been demonstrated in the left hemisphere by Luria, and some speech functions are dependent upon it.

The paradox cannot be resolved here, and must await future research which involves extensive testing of the brain-damaged. A possible though complex solution is that nature of processing varies within and between hemispheres. Thus, the fronto-temporal regions of the left hemisphere are 'more' successive or sequential than those of the right and the parietal-occipital regions of the right are 'more' simultaneous or parallel than those of the left. Such an arrangement, if genetically determined to some extent, might account for the development of language by the left hemisphere, and the different neuroanatomical arrangements of the two hemispheres (Semmes, 1968). Such solutions also tend to beg the question.

Summary

Two information processing analyses of brain function, both of which involve distinctions between types of processing, and Luria's three block structural model of the brain were discussed. Because the relations between Luria's work and that on laterality differences are still unclear, no resolution was presented. Aspects of Luria's model, particularly simultaneous and successive processing, will be further examined, in a different context, in the next section.

Factor Analytic Studies of Simultaneous and Successive Processing

In an attempt to demonstrate the existence factor-analytically of Jensen's Level I and Level II abilities in normal and retarded children, Das (1972) found two factors which could more parsimoniously be described as Luria's simultaneous and successive syntheses. In a series of subsequent studies (Das, 1973a, 1973b; Das & Molloy, 1975; Krywaniuk, 1974; Leong, 1974; Jarman, 1975; Williams, 1976), tests have been added to and taken away from the battery originally used, and the battery has been used with samples from different age, ethnic, socioeconomic status and ability groups (see Das, Kirby & Jarman, 1975, for a review).

The actual tests used will be described more fully in a later chapter, but a representative factor analysis can be seen in Table 1. The four factors which emerged (Das, 1973a, p. 47) were identified as, respectively, successive processing, school achievement, simultaneous

Table 1

Rotated Factors (Varimax) for Cognitive and Achievement Tests: Edmonton High and Low SES Children (N = 60) (from Das, 1973a)

	I	II	III	IV
Variable	Successive	School Achievement	Simultaneous	Speed
Verbal IQ (from school records)	347	793	204	045
Raven's Matrices	181	384	740	200
Figure Copying	162	157	674	004
Memory for Designs*	178	-055	-830	-162
Cross-modal Coding	457	059	433	423
Visual Short-Term Memory	760	034	124	462
Serial Recall	896	355	042	013
Free Recall	898	340	004	019
Word Reading	-130	-320	045	-879
Reading Achievement	184	851	100	266
Math Achievement	161	844	281	152
% of total variance	24.4	23.5	18.5	12.1

*In this analysis, Memory for Designs is an error score, producing negative loadings.

processing, and speed.

The first factor (successive) is related to Serial and Free Recall, which are alternate scorings of the same auditory short-term memory test for words, and Visual Short-Term Memory for numbers. It is therefore not a modality specific factor. However, nor is it fully a general memory factor. Memory for Designs, a short-term memory test for geometric pictures, does not load highly on this factor. What the three tests that load on this factor do have in common is a sequential or successive ordering of elements. In other studies (e.g., Das & Molloy, 1975), Digit Span has also been found to load on this factor.

School record IQ (Verbal), reading achievement and mathematics achievement load highly on the second factor, which can thus be best identified as a school intelligence or school achievement factor.

Were it not for IQ loading highly on the second factor, the third factor might be interpreted as 'reasoning', because of the high loading of Raven's Progressive Matrices. Since Memory for Designs also loads highly on this factor, however, it cannot be strictly reasoning, but must rather be something common to both reasoning and memory tests. What the tests do share is a need for processing whole patterns at once, rather than as a series of details; in other words, simultaneous processing.

The fourth factor is essentially a singleton, being related mainly to word reading speed. It has been tentatively interpreted as a speed factor. This has been confirmed in other studies (e.g., Das & Molloy, 1975) where color naming speed also loads on this factor.

When replicated with low ability children (Das, 1972; Jarman, 1975), disabled readers (Leong, 1974), Oriya children from India (Das, 1973a), Canadian Indians (Krywaniuk, 1974) and Canadian blacks (Das, 1973a), the same factors were identified, but important differences in factor loadings for the simultaneous and successive factors were identified. These differences encouraged Krywaniuk (1974) to institute a remedial program designed to alter the factor loadings of the successive tests, in order to bring them closer to the loadings for white children. Not only was he successful in altering the loadings, but absolute performance in these tasks also improved significantly. The results of this remediation program support the interpretation of the two factors (simultaneous and successive) as cognitive processing strategy factors.

Two more factor analytic studies should be mentioned, in which similar factors can be inferred even though the tests were different. Cummins (1973) factor analyzed a battery of entirely different tests (paired associate learning tasks for concrete and abstract words, memory span for digits, concrete and abstract words, logical syllogisms, similarities, paper folding, and three divergent thinking tests) given to high school students. He found first a divergence factor, secondly a simultaneous, and thirdly a successive processing factor. Simultaneous processing was related to solving logical syllogisms (Huttenlocher [1968] has indicated that spatial processing is involved in this task), finding similarities between different objects, visualizing the results of folding paper, and remembering lists of paired associate concrete words. Successive processing was related to the memory span tests for digits, concrete words and abstract words, and for remembering lists of paired associate abstract words.

One final element of supporting evidence is a study of memory by

Bergan, Zimmerman and Ferg (1971). They presented subjects with lists of numbers, words or simple figures which were to be recalled in correct order. Stimuli were presented either one or two or three at a time. In a subsequent factor analysis (wherein intelligence test data were included), three factors were found: memory for multiple units, memory for single units, and intelligence. The first two factors are clearly related respectively to simultaneous (two or more stimuli 'chunked' together) and successive (one by one) processing. Again, IQ defined a separate factor.

While none of the individual studies is without fault, similar factors have been found often enough to agree with Leong (1971, p. 335) that "there are statistical and psychological realities to the simultaneous-successive dimensions". Much of the existing evidence has been reviewed by Das, Kirby and Jarman (1975). Their model, which represents other studies of perception and memory as well, is illustrated in Figure 1. Briefly, information of any modality is received and temporarily stored in a sensory register (cf. Sperling, 1960) where it decays quickly if not further processed. The central processing unit, equivalent to the human cortex, consists of Luria's second and third blocks of the brain. Input is processed (encoded, recoded, stored) in the second block according to plans and decisions made by the third block. That processing is simultaneous or successive, and takes place at the perceptual, memory and conceptual levels. With reference to other models of information processing (e.g., Atkinson & Schiffrin, 1968), short- and long-term memory are storage structures within block two, while executive or control processes are regulated in block three.

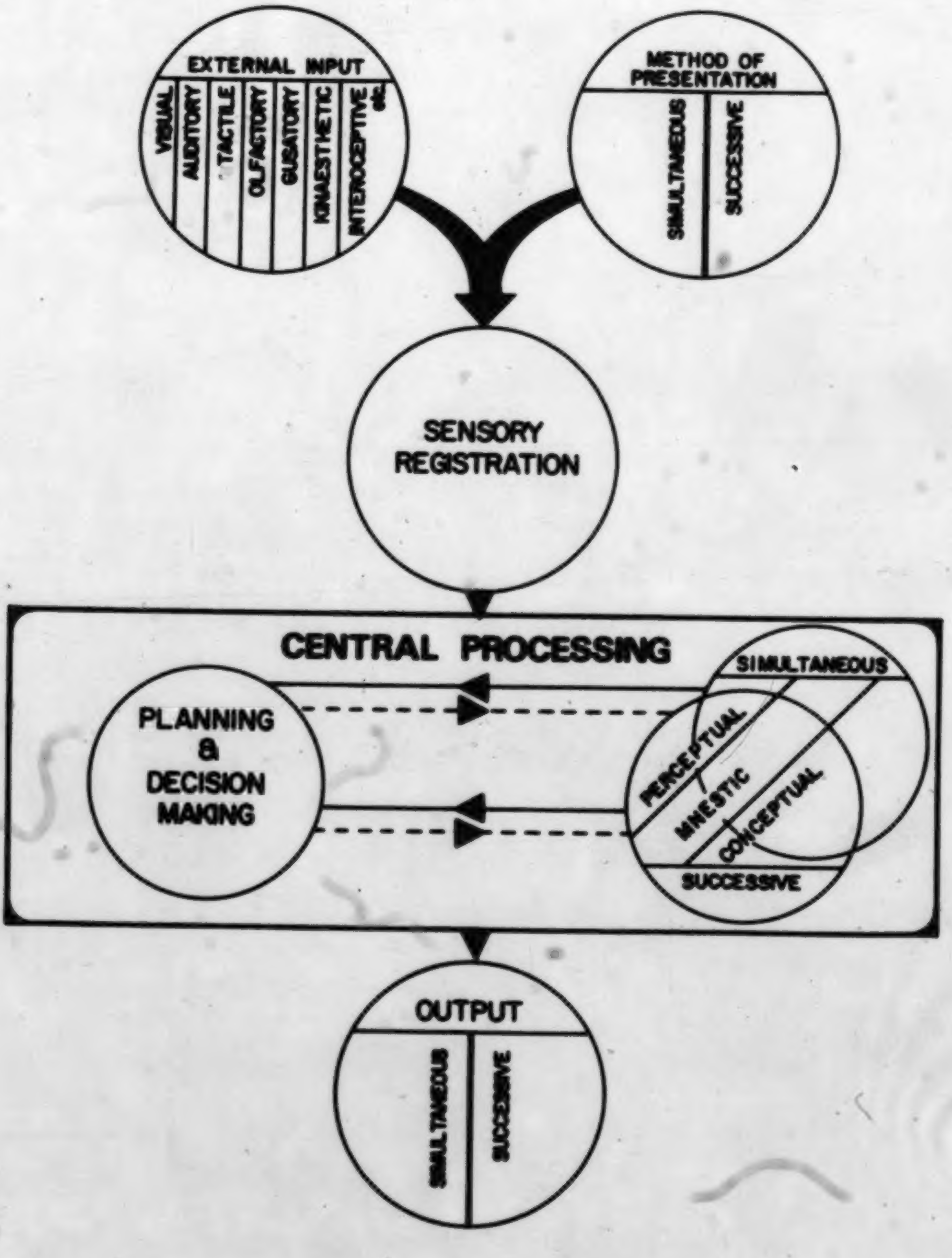
EXTERNAL INPUT
VISUAL
AUDITORY
TACTILE
OLFACTORY
GUSTATORY
KINAESTHETIC
INTEROCEPTIVE etc.
METHOD OF PRESENTATION
SIMULTANEOUS
SUCCESSIVE
SENSORY REGISTRATION
CENTRAL PROCESSING
PLANNING & DECISION MAKING
SIMULTANEOUS
PERCEPTUAL
MNESTIC
CONCEPTUAL
SUCCESSIVE
OUTPUT
SIMULTANEOUS
SUCCESSIVE

Fig. 1. The simultaneous and successive processing model of information integration (from Das, Kirby & Jarman, 1975, p. 90)

The form of output is theoretically independent of mode of processing, and can be either simultaneous or successive.

Relations with Paivio and Denney

This processing model can also be related to Paivio's (1975) imagery theory (Das, Kirby & Jarman, 1975, p. 99; Kirby & Das, 1976) and to the paradigmatic-syntagmatic research reviewed by Denney (1974a). Paivio (1975, 1976) states that imagery involves synchronous (simultaneous) processing, which is supported factor-analytically by Cummins (1973). While the Das et al. model suggests a relationship between imagery and verbal tasks on the one hand, and mode of processing on the other, it admits the possibility of either mode of processing being involved in either kind of task.

The model has also been related to the paradigmatic-syntagmatic distinction (Luria, 1973b). In an unpublished study (Kirby, Jarman & Das, 1975) two free recall clustering tasks were administered to a group of high IQ children, along with six of the simultaneous-successive tests. The lists for the clustering task were composed of the word lists of Denney and Ziobrowski (1972); one had paradigmatic pairs in random order and one syntagmatic. Subjects were asked to recall as many words as possible, in any order; responses were scored for number of clusters (i.e., number of related pairs that occurred adjacently). Results can be seen in Table 2.

The three factors can be identified as simultaneous and successive processing, and speed. Paradigmatic clustering loads as expected on simultaneous processing. Syntagmatic clustering does not load as expected, i.e., positively on successive. Instead, it loads positively

Table 2

Principal Components Analysis (Varimax Rotation)
from Kirby, Jarman & Das (1975)
(N = 52 nine-year-old children
Verbal IQ range: 110-130)

Variable	I Simultaneous	II Successive	III Speed	h^2
Raven's Matrices	686	-131	140	508
Figure Copying	513	-175	-317	395
Memory for Designs[1]	-706	-123	195	552
Serial Recall	-31	707	369	636
Visual Short-Term Memory	-117	768	-027	605
Word Reading	050	-156	-836	726
Syntagmatic Clustering	228	-502	489	543
Paradigmatic Clustering	580	-111	210	392
Variance	1.638	1.441	1.277	4.356
% of total variance	20.48	18.01	15.96	54.45

[1] error score

on speed, and negatively on successive. The results, while strongly suggestive of a meaningful relationship between the clustering task and the Das battery, defy definitive explanation. One possible explanation of the negative loading on successive is that the other successive tests require the maintenance of input order, while syntagmatic clustering requires that that order be broken, which is at best *post hoc*.

Relations with abilities

Although the first incidence of simultaneous and successive processing factor-analytically (Das, 1972) happened in the context of an attempt to replicate Jensen's Level I and Level II abilities, relations between simultaneous and successive processing and traditional abilities models have not been pursued systematically. Das, Kirby and Jarman (1975) suggested that abilities underlay processes, that they were structures which provided a lower boundary for the processes. Evidence presented above demonstrates that they (the processes) are independent of school achievement. The nature of the tests which define the processing factors, however, also suggests that these processing factors may be related to the psychometric factors discussed previously.

Summary

An elaboration of Luria's model was presented, based upon factor analytic work with a variety of samples (Das, Kirby & Jarman, 1975). Possible relationships were indicated between this model and those of Paivio and Denney. It was also suggested that simultaneous and successive processing may be related to the psychometric variables presented earlier. The exploration of these relationships provides the rationale for the study which is given in the next chapter.

CHAPTER III

A RATIONALE FOR THE STUDY

A number of alternate conceptions of mental ability were reviewed in the preceding chapter. The rationale behind the present study is an attempt to compare and relate these different conceptions and to discover the relations which exist between the constructs posited by the different theories. Throughout, the emphasis will be upon the simultaneous-successive processing model, and in general on attempts to develop an information processing model of human cognitive variability.

The first section of the last chapter reviewed traditional theories of abilities and concluded with a six factor, higher order summary of cognitive abilities. The pragmatics of testing a large number of school age children, however, dictate that only a small number of tests can be selected. Accepting a subjects-to-test ratio of, say, seven, and a tests-to-proposed-factors ratio of two (figures which are common but arbitrary), an adequate coverage of the six factors would require a sample of several hundred before the additional variables were added. Because several of the abilities factors were not of central concern, it was decided to construct a PMA battery (as this battery will henceforth be called) that would tap Gf (through Inductive Reasoning), Gv (through Spatial Ability), and M (through Memory). An indication of Gc could be obtained from school records (Verbal IQ, reading tests). VPT and Gs were not included.

The simultaneous-successive battery was easier to choose. Three tests of simultaneous processing, three tests of successive processing, and two tests of speed were selected. To examine the relationship of this battery to Paivio's and Denney's constructs, tests of Concrete and Abstract, Paradigmatic and Syntagmatic paired associates were added.

While no explicit hypotheses will be offered, the Reasoning-Spatial-Memory (or Gf-Gv-M) structure is expected to emerge from the PMA battery, and the simultaneous, successive and speed factors from the Das battery. In relating these batteries, several possibilities arise: the processing factors could be essentially uncorrelated with the abilities factors, suggesting that in some fundamental sense they underlie the abilities. A second possibility would be, as Jensen might suggest, that the simultaneous and successive factors are the same as two of the PMA factors, Reasoning and Memory; this would produce a relatively high correlation between those factors. The third possibility is that there will be moderate correlations (below say .4) among the various factors, suggesting that they are related but by no means isomorphic.

The Concrete, Abstract, Paradigmatic and Syntagmatic tests are included for the purposes of exploration. Existing literature suggests possible relationships with the simultaneous-successive, but these have not yet been convincingly demonstrated.

The PMA battery, the simultaneous-successive battery, the Concrete-Abstract tests, and the Paradigmatic-Syntagmatic tests represent four different conceptions of cognitive ability or variability. It is hoped that the present study will uncover the relationships existing among these different models, and will allow some conceptual, theoretical integration to begin.

CHAPTER IV

METHOD

Subjects

The principals and teachers of five urban elementary schools consented to participate in the study. As four of the schools had two classes each, a total of nine regular Grade 4 classrooms was available for testing. Even though the males were the main object of the study, all tests were also administered to the females. A small number of children (9 males, 13 females) did not complete all tests and were not included in the samples. As a result, a total of 104 males and 98 females were tested.

The schools represented a good cross-section of the city, ranging from rather low middle class to relatively upper class schools. Age and IQ data for each school and for the total sample can be seen in Table 3.

Tests and Procedure

Test materials

The following tests were administered to all subjects. All tests except Digit Span, Word Reading and Color Naming, which were given individually, were given to classroom-sized groups. Except where otherwise indicated, tests were scored for number of items correct.

Raven's Coloured Progressive Matrices (RPM). A traditional test of general, nonverbal reasoning (Raven, 1938, 1965) or of fluid intelligence (Cattell, 1971), it has been found by Das (e.g., 1972)

Table 3

Means and Standard Deviations of Age, Verbal IQ and Nonverbal IQ for Five Schools and Total Sample (N = 104 males)

School	N	Age*		IQs** Available for (N)	Verbal IQ**		Nonverbal IQ**	
		Mean	SD		Mean	SD	Mean	SD
A	19	110.6	3.7	19	97.4	16.4	104.8	19.1
B	20	108.6	4.3	13	106.3	16.8	112.5	16.9
J	16	112.5	6.4	14	88.6	13.8	97.7	17.5
M	19	109.2	6.1	19	111.1	14.8	113.2	10.8
S	30	109.7	3.7	30	104.0	15.4	112.6	16.5
Total	104	110.0	4.9	95	102.1	16.7	108.9	16.9

*Age is in months

**IQs are derived from the Lorge-Thorndike, which was administered by the School Board within one month of the other testing described in this chapter. IQs were not available for all test subjects.

to be a marker for simultaneous processing. The subject is required to indicate which of six alternatives correctly completes a given nonverbal pattern.

Figure Copying (FC). Developed by the Gesell Institute (Ilg & Ames, 1964), this test requires the subject to simply copy geometric figures while they are in view. Each of 10 drawings is scored as 0, 1, or 2 according to the degree of correctness of reproduction. Scoring criteria (available in Leong, 1974) emphasize the maintenance of geometric relations and proportions rather than exact reproduction. This test normally loads on simultaneous processing.

Memory for Designs (MFD). This test was originally devided by Graham and Kendall (1960) to detect minimal brain damage. Subjects inspect simple geometric figures for 5 seconds, and after the figure has been removed are required to draw each from memory. Each of 15 figures is presented separately by means of a Kodak Carousel Projector, and scored 0, 1, 2, or 3 according to the correctness of the reproduction. As in Figure Copying, drawings are scored for the maintenance of relations and proportions rather than for the presence and accuracy of details. It normally loads on simultaneous processing.

Serial Recall (SR). Twenty-four lists of four words are played over a tape recorder. After each list, the subject is immediately required to write in the correct order as many of the words that he can recall. Twelve of the lists are composed of unrelated words and 12 of words which are acoustically similar (e.g., tap, cap). This test is normally administered individually with oral responses. It is a test of successive processing.

Visual Short-Term Memory (VSTM). Subjects view a five-digit grid projected by a Kodak Carousel Projector for 5 seconds. Upon removal of the slide, the class is required to read an indicated item from a list of colors (filler task). They are then permitted to recall as many of the digits as possible in an empty grid, in the correct positions. There are 20 grids. This is a test of successive processing.

Digit Span (DS). Subjects are read lists of digits of increasing lengths. They are given two opportunities to successfully recall in correct order at each list length. Their score is the maximum list length recalled. This test has been used infrequently in the Das battery (Molloy, 1973; Cummins, 1973) but should load on successive processing.

Word Reading (WR). Subjects are required to read the names of four colors presented 10 times each in random order (40 words in all) on a slide projected by a Kodak Carousel Projector. The projected image was approximately 55 cm x 35 cm. Subjects were instructed to "read all the words, as quickly as possible, without making any mistakes", and were timed with a stopwatch. The test (Stroop, 1935) loads on the speed factor.

Color Naming (CN). This test (Stroop, 1935) is similar to Word Reading with the exception that the colors on the slide are strips of color, not words. The score is the number of seconds taken to read all 40 strips, and this test usually loads on speed.

Figure Grouping (FG). This is a test of reasoning from the Science Research Associates (SRA) Primary Mental Abilities Kit (Thurstone & Thurstone, 1962). The subject is required to select which of four figures is unlike the others and indicate his answer on an IBM answer sheet.

Word Grouping (WG). Another reasoning test from the SRA kit, this test requires the subject to select which of four words is unlike the others and indicate his answer on an IBM answer sheet.

Spatial Relations (SpR). This test of spatial ability is from the SRA kit and requires the child to select which of four shapes, when added to a given shape, will form a square. Answers are placed on an IBM answer sheet.

First and Last Names (FLN). This test was selected from the French, Ekstrom and Price (1963) Kit of Reference Tests for Cognitive Factors. It is a test of associative memory which requires the subject to study a list of 15 first names paired with last names for three minutes. Subjects then have two minutes to write as many of the first names beside the appropriate last names which appear on a second sheet of paper in scrambled order.

Word-Number (WN). This test is another test of associative memory from the French (1963) kit. Subjects study a list of 15 numbers paired with words for three minutes and then have two minutes to write as many of the numbers beside the appropriate words which appear on a second sheet of paper in scrambled order.

Figure Test (FT). This test of inductive reasoning from the French kit requires subjects to classify figures in terms of groups presented to them. They indicate their responses (group A or group B) on an IBM answer sheet.

Card Rotations (CR). This test of spatial ability is taken from the French kit. Subjects are required to indicate whether given figures have been rotated within the same plane, or flipped over. Answers are placed on an IBM answer sheet.

Concrete Paired Associates (CPA). Sixteen concrete nouns were selected from the norms assembled by Paivio, Yuille and Madigan (1968) and randomly assigned to pairs. Each word had an average frequency of at least 1:10,000 (so that each would be familiar to the subjects) and the list as a whole had an average concreteness value of 6.68 (range 5.50-7.00 on a seven point scale). The list was tape recorded with a one-second interval between words and a four-second interval between pairs. Subjects were instructed to listen to the pairs of words because they would have to recall which word went with each first word immediately afterwards. The stimulus members of the pairs were then presented to the subjects in scrambled order on a response sheet. They had one minute to write as many as they could remember. The concrete word list can be seen in Table 4.

Abstract Paired Associates (APA). Sixteen abstract nouns were selected from the Paivio et al. (1963) lists and randomly assigned to pairs. As in the CPA, each word had an average frequency of at least 1:10,000. The average concreteness of the list was 2.27 (range 1.18-3.41 on a seven point scale). The task was presented in a similar manner to the CPA task. Word lists can be seen in Table 4.

Paradigmatic Paired Associates (PPA). The paradigmatic (similarity) lists of Denney and Ziobrowski (1972) were used to construct eight pairs of words which were paradigmatically related. The list was equated for frequency and associative frequency with the

Table 4

Concrete, Abstract, Paradigmatic and Syntagmatic
Paired Associate Word Lists

Concrete	Abstract	Paradigmatic	Syntagmatic
newspaper - fire	interest - mind	high - tall	tobacco - pipe
arm - baby	idea - moment	king - ruler	chair - sit
animal - ship	hope - fact	priest - minister	examine - doctor
river - winter	history - chance	cold - warm	street - walk
door - dress	power - thought	wish - want	bird - fly
tree - rock	dream - honor	ocean - sea	music - piano
mother - house	joy - time	blossom - flower	net - catch
party - dog	cost - opinion	sheep - lamb	mix - cake

syntagmatic paired associate task. The task was presented in a manner similar to the CPA task. Word lists can be seen in Table 4.

Syntagmatic Paired Associates (SPA). The syntagmatic (complementary) lists of Denney and Ziobrowski (1972) were used to construct eight pairs of words which were syntagmatically related. Frequency and associative frequency averages were similar to those of the PPA list. The task was presented in a manner similar to the CPA task. Word lists may be seen in Table 4.

Procedure

All testing was done in the schools. Classroom testing took place in either the class' regular classroom or, in the case of open-area schools, in an available enclosed classroom with which the students were familiar. Individual testing took place in any available quiet room. Each child received all of the tests within no more than a one-month period.

The actual order or sequence of testing was constrained by the school personnel involved. Because schools in general wanted complete class periods (which varied in length both between schools and at different times of the day) rather than partial class periods to be occupied, test sequences were arranged differently for each school. Schools also differed with regard to the availability of time: in some schools testing was completed within one week, while in others only one hour of testing was available per week. Therefore, while total individual testing time (approximately four minutes per child) and total group testing time (approximately three and one-half hours per class) were constant for all classes, each class received a different order of tests which had not been randomized in any systematic manner.

CHAPTER V

RESULTS

The results of this study will be presented in four sections. The first two sections will deal with the simultaneous-successive battery and the PMA battery separately. The data for males will be analyzed for each battery; some alternatives concerning scoring of tests, inclusion of tests, and rotation of factors will be presented, and factors and factor scores for each battery will be generated. Section three will deal with the relations between these two batteries and among their factors. The fourth section will examine the relationships of the remaining variables (concrete, abstract, paradigmatic and syntagmatic paired associates) with the factors of the simultaneous-successive battery. In analyzing the batteries separately, the aim will be to demonstrate the existence of the factors that have been shown by previous research to emerge from those batteries. Because of the complexity of relationships that will emerge from the data, in relating the various tests and factors no single pattern will be demonstrated. Instead, a variety of relationships will be demonstrated, by a variety of methods.

The Simultaneous-Successive Battery

The means and standard deviations for the eight simultaneous-successive tests can be seen in Table 5, and their intercorrelations in Table 6. These correlations were submitted to a principal components analysis, and the three factors whose eigenvalues were greater than 1.0

Table 5

Means and Standard Deviations of Eight Simultaneous-Successive Tests (N = 104)

Variable	Mean	SD
Raven's Matrices	28.55	4.39
Figure Copying	13.60	2.92
Memory for Designs	42.23	2.63
Serial Recall	54.42	12.98
Visual Short-Term Memory	77.09	15.63
Digit Span	5.34	0.94
Word Reading	21.87	4.09
Color Naming	33.36	6.77

Table 6

Intercorrelations of Simultaneous-Successive Tests (N = 104)

	RPM	FC	MFD	SR	VSTM	DS	WR	CN
Raven's Matrices (RPM)	1.000							
Figure Copying (FC)	.421	1.000						
Memory for Designs (MFD)	.407	.405	1.000					
Serial Recall (SR)	.295	.280	.379	1.000				
Visual Short-Term Memory (VSTM)	.273	.320	.121	.538	1.000			
Digit Span (DS)	.082	.177	.102	.362	.465	1.000		
Word Reading (WR)	-.148	-.104	-.007	-.306	-.377	-.258	1.000	
Color Naming (CN)	-.127	-.043	-.152	-.139	-.041	-.074	.477	1.000

were rotated according to a Varimax criterion. Previous research (Das, Kirby & Jarman, 1975) also dictated the extraction of three factors. The analysis can be seen in Table 7.

With the exception of the loading of Serial Recall upon the factor identified as simultaneous processing, Table 7 conforms closely to the pattern established in previous research. Simultaneous processing is defined by Raven's Matrices, Figure Copying and Memory for Designs; successive processing by Serial Recall, Visual Short-Term Memory and Digit Span; and speed by Word Reading and Color Naming. The anomalous loading of Serial Recall upon simultaneous processing is explained by the fact that recall of the Serial Recall list in the present study was in writing; in past research the test was given individually and responses were given orally. By requiring written responses, the task allowed subjects to think in terms of four 'slots' or columns on their answer page, which were to be filled with appropriate items. Casual examination of the response sheets indicated that a large number of subjects did organize their answers in this way, often leaving blanks for missing words. This assigning of words to 'slots' would be more difficult with a verbal response, and probably contributes a spatial characteristic to the task. The major loading, however, remained on successive processing.

Because the speed factor was not a crucial component of the model, a further analysis was performed on the simultaneous-successive battery, excluding the Word Reading and Color Naming tests (Table 8). Previous research suggested the extraction of two factors, and this was confirmed by the number of eigenvalues greater than 1.0. These two factors are very similar to the first two factors of Table 7, simultaneous and successive processing.

Table 7

Principal Components Analysis with Varimax Rotation of Simultaneous-Successive Battery (N = 104)

Variable	Factor			
	Successive	Simultaneous	Speed	h^2
Raven's Matrices	104	753	-120	593
Figure Copying	245	713	057	572
Memory for Designs	011	810	-054	660
Serial Recall	642	402	-154	598
Visual Short-Term Memory	838	187	-076	742
Digit Span	785	-014	-045	618
Word Reading	-407	025	771	761
Color Naming	078	-122	904	837
Variance	1.972	1.945	1.464	5.381
% of total variance	24.6	24.3	18.3	67.2

Table 8

Principal Components Analysis of Simultaneous-Successive Battery (excluding WR and CN) with Varimax Rotation (N = 104)

	Factor		
Variable	Simultaneous	Successive	h^2
Raven's Matrices	772	106	608
Figure Copying	715	218	559
Memory for Designs	793	052	632
Serial Recall	392	678	614
Visual Short-Term Memory	189	828	722
Digit Span	-045	816	668
Variance	1.928	1.874	3.802
% of total variance	32.1	31.2	63.3

The PMA Battery

The means and standard deviations for the seven PMA tests can be seen in Table 9, and their intercorrelations in Table 10. As will be explained below, alternate scoring procedures were later employed for the Figure Test (FTc) and the Card Rotations test (CRc),and these variables also appear in Tables 9 and 10.

The seven original variables (i.e., including FT and CR, but not FTc and CRc) were entered into a principal components analysis. While only two eigenvalues were greater than 1.0, previous research suggested the extraction of three factors. Also, previous research had employed oblique rotations. It was decided to attempt both orthogonal and oblique rotations of both two and three factors (Tables 11 and 12).

In the two-factor solution, the first factor in either the orthogonal or oblique case can be seen to be defined by the tests that were hypothesized to define the Reasoning and Spatial factors. The second factor is loaded upon highly by the two Memory tests, but to a lesser extent also by the Figure Test (supposedly a test of Reasoning) and, in the orthogonal rotation, Card Rotations (a test of Spatial ability). The oblique two-factor solution is to be preferred to the orthogonal because its structure is more simple, but even it is less than satisfactory. The loading of the Figure Test on Memory is anomalous, and the Reasoning and Spatial dimensions have collapsed into one.

Both three-factor solutions are preferable to the two-factor. More variance is of course accounted for, and the structure is far simpler. There are no important differences between the orthogonal and oblique

Table 9

Means and Standard Deviations of Seven PMA Tests
with Alternate Scoring of Two Tests
(FTc and CRc)

Variable	Mean	SD
Figure Grouping	17.15	2.76
Word Grouping	15.86	4.11
Spatial Relations	17.51	4.36
First-Last Names	5.88	2.87
Word-Number	4.18	2.87
Figure Test	27.42	11.75
Card Rotations	25.65	12.07
Figure Test (corrected)	21.67	11.51
Card Rotations (corrected)	20.25	13.29

Table 10

Intercorrelations of Seven PMA Tests, with Alternate Scoring of Two Tests
(FTc and CRc)

	FG	WG	SpR	FLN	WN	FT	CR	FTc	CRc
Figure Grouping (FG)	1.000								
Word Grouping (WG)	.373	1.000							
Spatial Relations (SpR)	.438	.343	1.000						
First-Last Names (FLN)	.283	.312	.309	1.000					
Word-Number (WN)	.151	.134	.183	.432	1.000				
Figure Test (FT)	.197	.267	.323	.357	.236	1.000			
Card Rotations (CR)	.282	.343	.486	.316	.242	.548	1.000		
Figure Test (corrected) (FTc)	.211	.256	.402	.309	.205	.878	.431	1.000	
Card Rotations (corrected) (CRc)	.385	.397	.591	.300	.182	.409	.889	.440	1.000

Table 11

Orthogonal (Varimax) and Oblique (Promax) Rotation of Two-Factor Solution of Seven PMA Tests (N = 104)

	Orthogonal Factors			Oblique Factors		
Variable	Reasoning/ Spatial	Memory	h^2	Reasoning/ Spatial	Memory	h^2
Figure Grouping	733	041	540	811	-199	540
Word Grouping	689	122	489	741	-095	489
Spatial Relations	747	196	596	788	-034	596
First-Last Names	267	728	600	119	710	600
Word-Number	-049	840	708	-263	938	708
Figure Test	416	547	472	330	462	472
Card Rotations	606	433	554	570	273	554
Variance	2.183	1.775	3.958	2.290	1.670	3.958
% of total variance	31.2	25.4	56.5	32.7	23.8	56.5
Correlations of factors:		Reasoning/Spatial		1.000		
		Memory		.490	1.000	

Table 12

Orthogonal (Varimax) and Oblique (Promax) Rotations of Three-Factor Solutions
of Seven PMA Tests (N = 104)

	Orthogonal Factors				Oblique Factors			
Variable	Reasoning	Spatial	Memory	h^2	Reasoning	Spatial	Memory	h^2
Figure Grouping	841	009	130	724	937	-223	019	724
Word Grouping	692	199	112	531	712	038	-011	531
Spatial Relations	636	431	076	596	580	328	-080	596
First-Last Names	294	217	738	678	199	067	706	678
Word-Number	014	105	887	769	-097	-014	923	769
Figure Test	070	849	207	799	-199	937	067	799
Card Rotations	290	815	119	762	067	854	-051	762
Variance	1.765	1.669	1.424	4.858	1.760	1.725	1.373	4.858
% of total variance	25.2	23.8	20.3	69.4	25.1	24.6	19.6	69.4
Correlations of factors:			Reasoning		1.000			
			Spatial		.508	1.000		
			Memory		.311	.358	1.000	

rotations. Identification of factors, however, becomes a problem. The first factor is defined by two tests of Reasoning (FG and WG) and one test of Spatial (SpR). The second factor is defined by one test of Reasoning (FT) and one test of Spatial (CR). If the labels Reasoning and Spatial are to be used, then the factor loaded upon highly by Word Grouping (a verbal test) should be called Reasoning and the other Spatial. This, however, is far from satisfactory.

As described in Chapter III, both the FT and CR tests were adapted from the French _et al_. (1963) kit, and were in their original form suitable for those in grade 8 and above. As adapted, they were certainly within the ability of the grade 4 students; the time limits, however, did impose limitations. Subjects' responses tended to be of two kinds: either they did relatively few (in the order of 20 to 30) questions and were correct most of the time, or they did all of the questions, seemingly in a random fashion after the first 20 or 30 questions. Older subjects might not have resorted to a guessing strategy, but the subjects of the present study evidently had. This guessing behavior was not shown in the other PMA multiple-choice tests (FG, WG and SpR).

The FT and CR scores were subsequently corrected for guessing. The number of incorrect answers was subtracted from the number of correct answers, producing two new test scores, FTc and CRc. The means and standard deviations of these new scores are included in Table 9, and their correlations with the other PMA scores in Table 10. Again, while only two eigenvalues were greater than 1.0, previous research suggested a three-factor solution. Two-factor orthogonal and oblique solutions were attempted, but suffered from the same fault as those described above: The Reasoning and Spatial dimensions were collapsed, and the new FTc continued to spread its loading anomalously. Three-factor orthogonal and oblique solutions were performed and are reported in Table 13.

While Table 13 is again an improvement, FTc continues to present problems. In the oblique solution, this supposed test of Reasoning loads negatively on the factor identified as Reasoning. Furthermore, the Spatial Relations and Card Rotations tests have loadings higher than expected on the Reasoning factor. In an attempt to clarify the situation, it was decided to eliminate the test that seemed to be causing the greatest difficulty, FTc. This test, it will be remembered, was a Reasoning test adopted from a version suitable for older children. The test involved the classification of figures into groups according to rules that the subject had to infer from examples. While older children of higher mental ability may very well follow this procedure in solving the test items, the test in the present sample seemed to involve much less inductive reasoning and more spatial ability. One explanation might be that subjects were mentally rotating or arranging the figures to be classified, and answering on the basis of how closely they resembled given examples. At any rate, the test by by no means as factorially simple as the French et al. (1963) kit indicated it was for older subjects. FTc was dropped from the battery, and a principal components analysis performed upon the remaining six tests.

While only two eigenvalues were greater than 1.0, three factors were extracted on the basis of previous research. Orthogonal and

Table 13

Orthogonal (Varimax) and Oblique (Promax) Rotations of Three Factor Principal Components Analysis of Seven PMA Tests, Including New Scorings FTc and CRc (N = 104)

	Orthogonal Factors				Oblique Factors			
Variable	Spatial	Reasoning	Memory	h^2	Spatial	Reasoning	Memory	h^2
Figure Grouping	147	804	104	679	-105	876	-004	679
Word Grouping	170	738	139	593	-061	790	037	593
Spatial Relations	667	460	080	663	610	330	-069	663
First-Last Names	193	291	752	687	050	215	722	687
Word-Number	085	009	882	785	005	-090	905	785
Figure Test (corrected)	845	-036	213	762	965	-304	098	762
Card Rotations (corrected)	717	422	073	698	681	274	-080	698
Variance	1.770	1.667	1.430	4.867	1.776	1.711	1.380	4.867
% of total variance	25.3	23.8	20.4	69.5	25.4	24.4	19.7	69.5
Correlations of factors:			Spatial		1.000			
			Reasoning		.532	1.000		
			Memory		.301	.273	1.000	

oblique analyses are reported in Table 14. Differences between the orthogonal and oblique rotations are small, but the latter is preferred for simpler structure and for having been typical of previous research. This analysis, the oblique rotation of the six PMA tests, is the one to be referred to in subsequent sections.

Relations Between Batteries

A variety of procedures will be used to demonstrate the relations which exist between the simultaneous-successive and PMA batteries: a factor analysis of the combined batteries, Tucker's interbattery factor analysis, and a correlation of the factor scores of each battery.

Factor analysis

The correlations among the simultaneous-successive battery tests have been shown in Table 6, and those among the PMA battery tests in Table 10. Table 15 contains the interbattery correlations. All of these correlations were subjected to a principal components analysis and a Varimax rotation (Table 16).

It can be seen in Table 16 that successive processing (factor II) and speed (factor IV) emerge much as they do in the simultaneous-successive battery. Factor I is defined by at least six tests and can be called simultaneous-reasoning-spatial. The loading of reasoning and spatial tests on the same factor could be expected, as the correlation between the reasoning and spatial factors (Table 14) was .560. Raven's Matrices, Memory for Designs and Serial Recall load on this factor, as they had on simultaneous processing (Table 7). Figure

Table 14

Orthogonal (Varimax) and Oblique (Promax) Rotations of Three Factor Principal Components Analysis of Six PMA Tests, Excluding FTc (N = 104)

Variable	Orthogonal Factors				Oblique Factors			
	Spatial	Memory	Reasoning	h^2	Spatial	Memory	Reasoning	h^2
Figure Grouping	481	093	549	541	360	-047	488	541
Word Grouping	169	106	898	847	-126	-054	1.000	847
Spatial Relations	872	135	149	801	949	018	-115	801
First-Last Names	157	749	343	704	-028	715	282	704
Word-Number	103	895	-060	815	031	940	-192	815
Card Rotations (corrected)	825	127	213	742	873	004	-023	742
Variance	1.736	1.416	1.297	4.449	1.763	1.388	1.298	4.449
% of total variance	28.9	23.6	21.6	74.2	29.4	23.1	21.6	74.2
Correlations of factors:			Spatial		1.000			
			Memory		.308	1.000		
			Reasoning		.560	.328	1.000	

Table 15

Correlations Between Eight Simultaneous-Successive Tests and Six PMA Tests*

Simultaneous-Successive Tests	PMA Tests					
	Figure Grouping	Word Grouping	Spatial Relations	First-Last Names	Word-Number	Card Rotations (corrected)
Raven's Matrices	355	297	508	285	073	402
Figure Copying	191	060	424	285	333	214
Memory for Designs	346	279	357	360	252	378
Serial Recall	206	440	300	446	284	317
Visual Short-Term Memory	109	240	239	290	355	224
Digit Span	092	217	134	161	281	186
Word Reading	-091	-227	-163	-120	-214	-170
Color Naming	-105	-270	-198	-220	-122	-263

*r (.05, two-tailed) = .195
r (.01, two-tailed) = .254

Table 16

Principal Components Analysis of Eight Simultaneous-Successive Tests and Six PMA Tests (Varimax Rotation) and First Unrotated Principal Component (N = 104)

Variable	Factor					First Unrotated Principal Component
	I	II	III	IV	h^2	
Raven's Matrices	680	103	237	055	532	620
Figure Copying	274	141	698	[illegible]7	606	550
Memory for Designs	535	-033	517	026	555	599
Serial Recall	340	635	259	-124	602	687
Visual Short-Term Memory	106	809	248	-041	728	577
Digit Span	036	767	070	-049	596	425
Word Reading	-029	-393	-042	721	676	-414
Color Naming	-174	102	-108	881	828	-361
Figure Grouping	689	021	081	-027	483	536
Word Grouping	600	335	-128	-299	578	590
Spatial Relations	740	089	238	-065	617	688
First-Last Names	291	165	596	-211	512	622
Word-Number	-066	283	728	-196	653	487
Card Rotations (corrected)	718	135	095	-195	580	659
Variance	2.969	2.087	1.931	1.557	8.545	4.501
% of total variance	21.2	14.9	13.8	11.1	61.0	32.1

Copying, which had loaded highly upon simultaneous processing, does not load highly upon factor I in Table 16. In that it is a less complex task than the others (requiring simple copying, but no memory or abstract reasoning), factor I would seem to indicate a relationship between the reasoning and spatial tasks of the PMA, and the more complex simultaneous processing tasks.

Factor III is defined by the less complex simultaneous tests (Figure Copying and Memory for Designs; the latter is more complex than FC, but less complex than Raven's Matrices) and by the PMA memory tests, a relationship which is unexpected and at first hard to explain. A strong relationship between the PMA memory tests and successive processing would have been easier to understand, but did not emerge from this analysis. One possible explanation would involve the nature of the paired associate tests. They require the formation of relationships (associations) between pairs of items. To the extent that this can involve chunking, and to the extent that chunking is an index of simultaneous processing (cf. the discussion of Bergan, Zimmerman and Ferg's [1971] paper in Chapter II), a relationship such as that demonstrated by factor III could be understood. This explanation, admittedly post hoc, will arise in further discussions of the relationships between the batteries and those between the simultaneous-successive battery and the concrete, abstract, paradigmatic and syntagmatic paired associate tests.

The results of the 14-test analysis indicate a broad simultaneous-reasoning-spatial factor and a simultaneous-memory factor, in addition to the successive processing and speed factors which normally emerge from the simultaneous-successive battery. It will be of particular interest that the simultaneous tests were related to the PMA memory tests and the successive tests were not. Factor analysis, however, is just one way of eliciting relationships between batteries.

Interbattery factor analysis

Another method for comparing test batteries is Tucker's (1958) interbattery factor analysis which, instead of analyzing the correlations among the tests of both batteries, makes use of the intercorrelations of the two batteries (i.e., the correlations of the tests of battery A with the tests of battery B). Tucker also suggests a significance test for the number of factors, which compares the variance accounted for by the factors extracted with the total variance of this intercorrelation matrix.

Tucker's interbattery method was used to analyze the intercorrelation matrix of the eight simultaneous-successive tests and six PMA tests. Because the second eigenvalue is small (.386), though significant according to Tucker's test, both one- and two-factor solutions are reported in Table 17. Tucker's chi-square significance test is presented in Table 18. Both one- and two-factor solutions are presented because the status of Tucker's significance test is not clear, the sampling distribution of that statistic being unknown.

The one-factor solution represents a general factor which is related to all or most of the tests of both batteries. Like the first unrotated principal component of the 14-test analysis, this would seem to indicate that the batteries share a general cognitive dimension, but it is otherwise uninteresting for the purpose of drawing out relationships between the batteries. The two-factor solution is more successful in this regard.

Table 17

Interbattery Factor Analysis (One- and Two-Factor Solutions)
of Eight Simultaneous-Successive Tests
and Six PMA Tests

	One-Factor Solution		Two-Factor Solution (Promax)		
Variable	I	h^2	I	II	h^2
Raven's Matrices	593	352	988	-374	554
Figure Copying	463	215	278	215	215
Memory for Designs	598	357	508	124	369
Serial Recall	609	371	131	524	396
Visual Short-Term Memory	443	196	-123	605	268
Digit Span	321	103	-149	501	159
Word Reading	-297	088	022	-344	107
Color Naming	-365	133	-203	-186	133
Variance	1.816	1.816	1.181	1.020	2.202
% of total variance	64.70	64.70	42.07	36.34	78.45
Figure Grouping	426	182	530	-054	251
Word Grouping	540	291	166	447	311
Spatial Relations	640	410	656	062	481
First-Last Names	597	357	250	427	365
Word-Number	483	233	-202	756	438
Card Rotations (corrected)	585	342	462	196	355
Variance	1.816	1.816	1.130	1.072	2.202
% of total variance	64.70	64.70	40.26	38.19	78.45
Correlations of factors:		I	1.000		
		II	.568	1.000	

Table 18

Tucker's Chi-square Test of Significance of Interbattery Factors

	Factor		
	I	II	III
Eigenvalue	1.815	.386	.311
Degree of freedom	48	35	24
Chi-square	371.90	56.74	32.46
Probability of chi-square	<.0001	<.01	>.05

The first interbattery factor in the two-factor solution is defined essentially by the simultaneous processing tests, and the nonverbal (FG, SpR and CRc) tests of the PMA battery. The second factor is defined by the successive processing tests, and by the verbal (WG, FLN and WN) tests of the PMA battery. The first factor confirms the relationship between simultaneous processing and visuospatial tasks that was found in the factor analysis of the 14 tests (Table 16). The second factor demonstrates the relationship between successive processing and the memory tasks, which had been expected but was not found in the large factor analysis. While the factor analysis had underlined the chunking nature of the PMA memory tasks, the interbattery factor analysis seems to stress another aspect of the memory tasks, their sequential, associative nature.

The second interbattery factor demonstrates a relationship which is surprising, though predicted by Luria's model. This is the relationship between successive processing and the Word Grouping test. WG had been selected as a test of inductive reasoning, one which required the inspection of a set of (verbal) stimuli and the noting of irregularities. As such, it should involve simultaneous processing, and this was demonstrated in the factor analysis of the 14 tests combined (Table 16). However, in that it involves language or the verbal system, Luria would suggest that it also involves successive processing. The second interbattery factor shows that, while successive processing is related to the memory tasks, it is also related to a complex verbal inductive reasoning task.

The interbattery factor analysis of the simultaneous-successive and PMA batteries demonstrates the robustness of the simultaneous and successive processing factors, and further delineates the complex relationships which exist between these two batteries. Yet more relationships will be demonstrated by means of the factor scores generated for each battery.

Factor score correlations

As Gorsuch (1974) suggests, the relating of factors derived from different batteries administered to the same individuals is perhaps best served by the calculation of factor scores for each of the batteries independently, and the calculation of the correlations between the factors of the two batteries. In addition, factor scores of each battery may be correlated with the tests of the other battery.

Tables 19 and 20 contain, respectively, the correlations of the simultaneous-successive battery factors with the PMA tests, and the correlations of the PMA factors with the simultaneous-successive tests.

Table 19

Correlations of Three Simultaneous-Successive Factors with PMA Tests*

Test	Factor		
	Simultaneous	Successive	Speed
Figure Grouping	375	065	-091
Word Grouping	262	248	-263
Spatial Relations	523	154	-155
First-Last Names	397	238	-150
Word-Number	222	345	-104
Card Rotations (corrected)	408	164	-219

*r (.01, two-tailed) = .254

Table 21 shows the intercorrelations of the two sets of factor scores. A conservative probability level (.01) is recommended for inspecting these correlations, as error is associated not only with the correlations, but also with the factor scores.

In Table 19, simultaneous processing is related to all of the PMA tests, with the exception of WN. Only WN is related to successive processing. Speed (i.e., latency) is related to poor performance on WG, suggesting that faster responding results in better performance on that test. In Table 20, the spatial factor is related to the tests of simultaneous processing, the memory factor is related to the successive tests and two of the simultaneous (FC and MFD) tests, and reasoning to

Table 20

Correlations of Three PMA Factors with Simultaneous-Successive Tests*

Test	Factor		
	Spatial	Memory	Reasoning
Raven's Matrices	525	187	386
Figure Copying	363	366	125
Memory for Designs	433	346	374
Serial Recall	338	413	456
Visual Short-Term Memory	247	384	233
Digit Span	173	268	193
Word Reading	-179	-201	-197
Color Naming	-243	-191	-267

*r (.01, two-tailed) = .254

RPM, MFD, SR and fast performance (i.e., low latency) on CN. Relations between successive and WG, and spatial and VSTM are of borderline significance.

In Table 21, a far more straightforward picture of the relationships between the two batteries is presented. These factor score correlation

Table 21

Correlations of Three Simultaneous-Successive Battery Factors (Varimax Rotation) with Three PMA Battery Factors (Promax Rotation)*

Simultaneous-Successive Battery Factors	PMA Battery Factors		
	Spatial	Memory	Reasoning
Simultaneous	541	345	376
Successive	165	350	215
Speed	-197	-143	-244

*r (.01, two-tailed) = .254

results can be summarized in three statements: simultaneous processing is primarily involved in spatial ability; simultaneous processing is equally involved in memory and in reasoning; and simultaneous and successive processing are equally involved in memory. Table 21, in effect, presents in summary form all of the results found by the various methods employed above. As a summary, it conceals the fine details of some of the relationships, for instance, the relationship demonstrated in Table 17 between successive processing and the verbal reasoning test. It is important for presenting concisely the major results of the study.

Summary

While the relations between the batteries were by no means simple, a number of major trends have recurred. First of all, the first unrotated factor of the 14-test analysis (Table 16) and the first unrotated interbattery factor (Table 17) suggest the existence of a common general cognitive factor. This result does little to clarify the relations which exist between the batteries.

Secondly, the tests of simultaneous processing are related to the PMA spatial tests and to the PMA reasoning tests, primarily the one that is nonverbal. This is shown by factor I of the 14-test analysis (Table 16), the first rotated interbattery factor (Table 17), and the correlations between factor scores (Table 21). This result confirms the spatial involvement of simultaneous processing. The weakness of the simultaneous-reasoning link argues against any unification of these two constructs.

A third trend is the relation between successive processing and a verbal-memory dimension. Evidence for this is found in the second rotated interbattery factor (Table 17), and the correlation between the successive and memory factors (Table 21). It is also suggested by the correlation between successive processing and WG, which is nearly significant (Table 19). Again, the weakness of the successive-memory relationship disallows an identification of either construct with the other.

The fourth finding is that simultaneous processing is related to the two paired associate tests, perhaps through the mechanism of chunking or coding. This is demonstrated by factor III of the 14-test analysis (Table 16), the correlation between the simultaneous and memory factors (Table 21), the correlation between simultaneous processing and at least one of the two paired associated tests (Table 19), and the correlations between the memory factor and at least two of the simultaneous tests (Table 20). This last finding implicates some well-known constructs in experimental psychology, and clarifies the nature of simultaneous processing as a coding process. All of these results will be discussed more fully in the following chapter.

Relations Between Simultaneous-Successive Battery and Concrete, Abstract, Paradigmatic and Syntagmatic Paired Associates

Simultaneous processing has been related to successful performance on the PMA paired associate tests. On the basis of theory and previous data, it might have been predicted that simultaneous processing would be involved in concrete and paradigmatic paired associates, and successive in the abstract and syntagmatic. Such did not prove to be the case.

The means and standard deviations of the four additional tests are in Table 22, and their correlations with the simultaneous-successive battery factors are in Table 23. What is immediately apparent from Table 23 is that the predicted relationships are not present. In an attempt to clarify what relationships did appear, two separate principal

Table 22

Means and Standard Deviations
of Concrete, Abstract, Paradigmatic
and Syntagmatic Paired Associate Tests

Variable	Mean	SD
Concrete	4.79	2.28
Abstract	1.21	1.26
Paradigmatic	4.47	1.77
Syntagmatic	6.06	2.14

Table 23

Correlations of Three Simultaneous-Successive Factors
with Concrete, Abstract, Paradigmatic and
Syntagmatic Paired Associate Tests*

Test	Factor		
	Simultaneous	Successive	Speed
Concrete	452	166	-214
Abstract	264	196	-213
Paradigmatic	225	354	-313
Syntagmatic	312	366	-063

*r (.01, two-tailed) = .254

components analyses were performed. The first included the concrete (CPA) and abstract (APA) paired associates with the simultaneous-successive battery, and the second included the paradigmatic (PPA) and syntagmatic (SPA) paired associate tests with the simultaneous-successive battery. These analyses are reported in Tables 24 and 25.

In Table 24, it can be seen that factors identifiable as simultaneous, successive and speed emerge. CPA loads mainly on simultaneous, but also on speed. APA loads equally upon simultaneous and speed. This demonstrates that performance in concrete and abstract paired associate tests does not necessarily involve, respectively, simultaneous and successive processing. In the light of the relationships found in the preceding section between simultaneous processing and the PMA paired associate tests, it seems best to invoke a similar explanation for the CPA and APA results. Because the words in each pair

Table 24

Principal Components Analysis (Varimax) of Simultaneous-Successive Battery with Concrete and Abstract Paired Associates

Variable	Factor			
	Simultaneous	Successive	Speed	h^2
Raven's Matrices	718	107	-076	533
Figure Copying	647	285	163	526
Memory for Designs	784	-002	-039	617
Serial Recall	457	594	-208	605
Visual Short-Term Memory	217	825	-097	737
Digit Span	-022	803	-041	647
Word Reading	034	-411	739	716
Color Naming	-083	069	846	728
Concrete	656	070	-336	548
Abstract	421	118	-430	376
Variance	2.421	1.963	1.648	6.033
% of total variance	24.2	19.6	16.5	60.3

Table 25

Principal Components Analysis (Varimax) of Simultaneous-Successive Battery with Paradigmatic and Syntagmatic Paired Associates

	Factor			
Variable	Successive	Simultaneous	Speed	h^2
Raven's Matrices	140	751	-105	594
Figure Copying	201	688	044	516
Memory for Designs	044	803	-079	653
Serial Recall	676	366	-191	627
Visual Short-Term Memory	806	138	-079	675
Digit Span	732	-055	-018	539
Word Reading	-372	062	770	736
Color Naming	106	-108	879	796
Paradigmatic	502	227	-457	513
Syntagmatic	570	364	-065	461
Variance	2.430	2.038	1.643	6.110
% of total variance	24.3	20.4	16.4	61.1

were essentially unrelated, success in remembering the pair was dependent upon forming the pair into some sort of chunk, which would require simultaneous processing. The relationship with speed, particularly for APA, is probably a function of the difficulty of the task: the faster one is at responding, the more words can be recalled. In CPA, where the chunks are easier to form, speed is less important.

The principal components analysis of the simultaneous-successive battery with PPA and SPA (Table 25) is also unclear. Both PPA and SPA are most related to successive processing, PPA being also related to speed, and SPA also to simultaneous. Again, the results are not as expected, and only post hoc explanations can be offered.

The relation of speed to PPA but not to SPA is probably a function of task difficulty, the more difficult task being more dependent upon speed of response. The loading of SPA on simultaneous would seem to be like the loadings of all previous paired associate tests, perhaps involving chunking. The loadings of both PPA and SPA on successive, however, suggest that something more is operative.

A more reasonable explanation of these findings could be based upon the nature of the word pairs. CPA and APA were composed of essentially unrelated words, while PPA and SPA word pairs had associative frequencies which ranged from five to 48 per cent (Denney & Ziobrowski, 1972). The loadings of these tests upon successive processing could, therefore, be a function of their average associative frequencies, higher associative frequencies implicating successive processing. When associative frequencies are low, success in the task is a function of how well the stimulus pairs can be coded together (chunked), and is thus a function of simultaneous processing. When associative frequencies are high, successful performance is a function of the recall of an over-learned association (successive processing). In either case, the more difficult the task, the more a speed factor becomes important. It is not clear from the results how speed affects performance: it could be that the speed of encoding (chunking) or of processing of input is important. Alternatively, simple response speed (who was quickest to pick up their pencil and write) could be the operative factor: quick responding would allow a 'read-out' from short-term memory (recency effect) independent of any recoding or established associative bonds.

The relationships observed between the various paired associate memory tests and the simultaneous-successive battery are more complex than those that might have been predicted from theory and previous data. They suggest strongly that paired associate memory cannot be identified with either simultaneous or successive processing. Furthermore, the manipulation of concreteness values for words (CPA, APA) does not necessarily determine whether simultaneous or successive processing will be used, nor does changing the type of association between words in each pair (PPA, SPA). The results reported here do not support the collapsing of the various models studied (PMA, simultaneous-successive, imagery-verbal, paradigmatic-syntagmatic) into one. Rather, they implicate a relatively complex pattern of relationships which form the basis for the discussion and theoretical integration that is to follow.

CHAPTER VI

DISCUSSION

Faith in a simple universe might have suggested that the simultaneous processing dimension could be equated with the inductive reasoning factor of the PMA, with Paivio's imagery processing, and with paradigmatic language processing. Similarly, successive processing would be identified with PMA memory, Paivio's verbal processing, and syntagmatic processing. Such findings would have been strong support for a two-category, high level-low level approach to cognition, in the same vein as Jensen's Level I-Level II distinction.

A second, qualitiatively different set of results would have shown the various conceptions of cognition to be unrelated. Such results, given the general relatedness (positive manifold) of cognitive tests, would have been surprising, but would have demonstrated the independence of the various dimensions.

Neither identity nor independence was found. The results could best be characterized as demonstrating a complex series of relationships between the simultaneous-successive battery and the other cognitive models. The meaningfulness of these relationships has implications for the nature of the constructs in the simultaneous-successive processing model, and for the theoretical integration of the many models of mental ability.

The results of the present study will be discussed in two chapters. This chapter will deal with the specific implications of the data collected for the models studied. Chapter VII will discuss the present status of the simultaneous-successive processing model, and attempt to extrapolate from it and other research in cognition an outline for a theory of cognition or of intelligence. Finally, problems associated with process models in psychology will be examined. Possibilities for future research will be presented as they become relevant.

Discussion of Results

The major emphasis of the study was a comparison of the factors emerging from the simultaneous-successive battery and from the PMA battery. A necessary prerequisite was the establishment of the two batteries.

The simultaneous-successive battery

The justification for the identification of the factors of this battery as simultaneous and successive processing and speed has already been offered in the review of the literature. Additional clues as to the nature of the constructs indicated by these factors will be found throughout the discussion of the results. A general review of the current status of these constructs will be presented in Chapter VII.

Previous principal components analyses of the simultaneous-successive battery (Das, 1972, 1973a, 1973b; Krywaniuk, 1974; Leong, 1974; Das, Kirby & Jarman, 1975; Das & Molloy, 1975; Jarman, 1975) have repeatedly shown the same factors to emerge. While none of these previous studies had large sample sizes, and factors were sometimes defined by only one test, the consistency of the resulting factor structures lends support for the three factors of the model: The present study also supports the three-factor model by replicating previous results, with a larger sample size and with a more complete battery.

Furthermore, the loading of Serial Recall on simultaneous processing, as well as on successive processing (see Table 7), though different from previous results, lends support to the model by being interpretable. In previous studies, this test was given auditorally, and the subject responded by saying out loud as many words as he could remember. In the present study, although the test was given auditorally, each subject wrote his responses on a sheet of paper. The four words of each list were to be written on a line, there being 24 lines. While vertical columns were not provided, some subjects seemed to form four columns, often leaving out a word they had forgotten. This observation is probably indicative of a more general tendency of subjects to think of each list as having four 'slots' which were to be filled with words. The use of columns on a page indicates a partly spatial strategy; the more general (inferred) four-'slot' strategy could be termed quasi-spatial. Both can be seen to involve what has been called simultaneous processing, the immediate surveying of a set of items. Accordingly, the loading of Serial Recall on simultaneous processing is meaningful.

The loading of Serial Recall also emphasizes a major theme underlying the present results, that certain sequential memory tasks, under certain test conditions, can elicit simultaneous processing, as well as successive. This theme is reminiscent of Miller's (1956) and Johnson's (1970) work on chunking, coding and the organization of free recall, and of Estes' (1974) discussion of how such complex processes could determine performance in a test as seemingly simple as Digit Span. The basis for the linking of chunking or coding with simultaneous processing is given by Johnson's (1970, p. 173) definition of a chunk as "any response set or sequence which is represented in memory by a single code". Clearly, what has been called simultaneous processing is involved in the formation of such an entity. Success in remembering paired associates, or any other sequence of arbitrary material, is aided by coding or chunking (Estes, 1974; Hunt & Lansman, 1975; Johnson, 1970, 1973; Miller, 1956) and by extension, simultaneous processing. This implication of simultaneous processing in coding is seen most clearly in the case of Serial Recall, but will also become evident in the relations between the simultaneous-successive battery and the PMA memory tests, and the concrete, abstract, paradigmatic and syntagmatic paired associate tests.

This process description of test performance emphasizes the likelihood that differences in overall mental ability, age, or familiarity with the task will lead different subjects to employ different strategies, giving rise to different levels of performance. Such a statement is potentially circular: it is possible, if not probable, that overall differences in, for instance, mental ability are a function of poor coding strategies (Ellis, 1970; Spitz, 1966).

Hunt and Lansman (1975) have also discussed the impact of coding or chunking strategies upon performance in what seem to be rote memory tasks. Their data suggest that implementation of a coding strategy is important, but not as easy as Estes (1974) believes, particularly when information is input rapidly.

In the light of previous work, the present results support a model in which coding processes are important, but in which their use may be hindered by such task factors as speed of input, form of response (oral or written), and arbitrariness of material, and by subject variables such as age or overall mental ability. It is thus possible that with older or more able subjects an hierarchical coding strategy involving simultaneous processing might be employed in the Serial Recall task, even when responses were oral.

The PMA battery

The Primary Mental Abilities factor structure was established with more difficulty. Interestingly, the difficulties could be related to strategy differences: tests that had been originally designed for older subjects, and adapted for younger ones, did not load as they had been shown to in the older subjects. The younger subjects, it seemed, were using other, less developed strategies such as guessing or spatial rotation in a task that required reasoning. (Here again one must be aware of potential circularities. Is the use of a different strategy also a function of different levels of ability in the process not employed? Problems in the inference of strategies or processes will be discussed in a later section.) In spite of these difficulties, a satisfactory PMA battery was established by eliminating one test (FT), and correcting another for guessing (CRc). This battery gave rise to three factors: reasoning, spatial and memory, the first two being relatively highly correlated (Table 14).

For the purposes of comparison, these three factors can be seen as the primary factors which they are, or as representative of the higher-order factors which Horn (1975) discusses. Thus, inductive reasoning would be an example of general fluid intelligence (Gf), spatial of general visualization (Gv), and memory of a general memory ability (M). This generalization to higher-order factors signifies the inference of more abstract constructs, an inference which is less certain than that involved in identifying the primary factors.

Relations between batteries

A variety of techniques was employed to illustrate essentially four kinds of relations between the two batteries. The first and least surprising was that a general factor (like Vernon's "g") underlay both batteries. Since both batteries consisted entirely of cognitive tests, this finding is not very informative.

A second relationship that was found was that between simultaneous processing on the one hand and spatial ability and inductive reasoning on the other. Because simultaneous processing has been described by Luria (1966b, p. 74) and by Das and his colleagues (Das _et_ _al_., 1975, pp. 89-91) as the integration of information into groups which have a spatial or quasi-spatial nature, its involvement in spatial ability confirms to some extent that aspect of simultaneous processing. Simultaneous processing is also required in both inductive reasoning tests: a set of stimuli (words or figures) must be held and an irregularity noted. This relationship of simultaneous to reasoning is weaker than that of simultaneous to spatial (e.g., Table 21). The relationship is also stronger for the nonverbal reasoning test (FG) than for the verbal (WG) test (e.g., Tables 17 and 19). This difference stresses the spatial nature of simultaneous processing. The lack of a strong relationship between simultaneous processing and the reasoning factor per se (Table 21) makes very doubtful any suggestion that simultaneous processing _is_ reasoning or Level II ability.

The third pattern that was evident in the data involved successive processing, the PMA memory factor and, to a lesser extent, the verbal reasoning test. What is most surprising about the relationship between memory and successive is its weakness. When factor scores are correlated, the correlation between these two was no higher than that between simultaneous and memory. Furthermore, when both batteries were factor analyzed as one, the PMA memory and the successive factors emerged separately, the former being related to a simultaneous processing or coding factor. That the relationship between the successive and PMA memory tests is very weak when variance due to the simultaneous-coding factor has in effect been partialled out, casts doubt upon the correlation between successive and memory factor scores. It could be that what correlation is evident (Table 21) between the successive and memory factors is due to a coding strategy involved particularly in the PMA memory tests and Serial Recall. The interbattery factor analysis also indicated a relationship between successive processing and the PMA memory tests, and extended it to include the verbal reasoning test (WG). Though it may be weak, this dimension appears to involve whatever is in common among tasks which require the temporal sequencing of stimulus items, those involving paired associate learning, and one involving verbal reasoning. While Luria (1966b, p. 78) and Das et al. (1975, pp. 89-91) assign to successive processing an important role in human speech and language comprehension, it is surprising that successive processing would manifest itself in such a task as Word Grouping. This task would seem to require little sequential processing, being more dependent upon the (simultaneous) surveying of a set of stimuli for irregularities. While no definitive explanation is available, an adequate one might be that, as Paivio (1971, 1975) and others (e.g., Nebes, 1974) have suggested, the verbal system is reliant upon sequential processes; as such, even the semantic information required in the WG task ~~might~~ be represented, to some extent, sequentially or successively. This representation could take the form of a semantic network whose links would be searched sequentially. This third trend in the data is weak, however. It shows that successive processing is involved to some extent in the memory and the verbal reasoning tests. The weakness of this relationship questions in particular the premise that the factor defined by the PMA memory tests is the rote, sequential memory that it is supposed to be.

The fourth relationship found in the data was suggested by the factor analysis of both batteries as one, and by the factor score correlations. Simultaneous processing, especially that aspect of it defined by Figure Copying and Memory for Designs, was shown to be related to performance in the PMA paired associate memory tasks. This finding, which suggests that the PMA rote memory tasks are not entirely tests of rote memory, is best explained by the simultaneous processing or coding hypothesis which has been presented previously. This implication of simultaneous processing in coding will help explain some of the results dealing with the concrete and abstract paired associate tasks, and will be an important element in the model to be presented in the following chapter.

If the three PMA factors are thought of as representative of Horn's higher-order factors of Gf (reasoning), Gv (spatial) and M (memory), then the results achieve a broader perspective. General visualization is seen as operating through simultaneous processing, in contrast to fluid intelligence, which is less reliant upon it. The PMA memory tests, however, do not appear to represent well the construct of general (associative) memory. Their susceptibility, at least in the present sample, to coding strategies seems to violate the basic principle of simple association. In fact, the results of the present study would suggest that, if a general factor relating to associations between items is sought, the factor identified as successive processing is a more promising candidate. The concept of successive processing would seem to encompass the essence of association, that is, the sequential ordering of items. The generality of this factor as a higher-order construct is evidenced by its relation to the WG test, and is theoretically supported by the important role it plays in speech and language comprehension.

Another way of considering the results is in the terms that Carroll (1974) extracted from Hunt's (1971, 1973) Distributed Memory Model. That model postulated three levels of storage beyond the sensory buffers: short-term memory (STM), which contains stimulus-bound codes for a matter of seconds; intermediate-term memory (ITM), which holds more meaningful codes for a number of minutes; and long-term memory (LTM), which is a permanent store of what is known about the world. It will be remembered that in classifying the PMA tests subjectively, Carroll (1974) suggested that performance in spatial ability tests was dependent upon the manipulation of STM contents, that success in the PMA memory tasks was a function of ITM codes, and that the tests of inductive reasoning relied more upon the existence of appropriate hypotheses in LTM.

With reference to the present study, the spatial (or Gv) tests are more dependent upon form of processing (simultaneous), and the other tests are less dependent upon processing. The formation of temporary ITM codes, as well as successive processing, plays an important role in the PMA memory tests, and the reasoning (or Gf) tests are related to something other than either form of processing. This extension of Hunt's memory model will help form the basis of the integrated model to be suggested later.

Relations with concrete and abstract paired associates

It will be remembered that, when the concrete and abstract paired associate tests were factor analyzed with the simultaneous-successive battery, these two tests loaded on simultaneous processing and speed. The prediction that CPA would load on the simultaneous factor stemmed primarily from an hypothesis not unlike that advanced to explain the results of the PMA memory tests. As described by Paivio (e.g., 1971), concrete paired associates are best learned by the formation of an image (a form of code) in which the objects represented by both words are present. According to imagery theory, abstract pairs cannot be learned this way, as they do not represent concepts of which an image can easily be formed. Paivio would suggest that recall of an abstract paired associate would have to rely upon a sequential, verbal association. If such were the case, APA should have loaded upon successive processing.

The results as they stand suggest that recall in both tests was a function of coding, of forming the words of each pair into some kind of unitary representation. It is unlikely that that representation is an image in the case of APA; therefore, the factor loadings suggest that what these tests have in common with simultaneous processing is not a particular form of unitary coding, but rather unitary (or hierarchical) coding in general. In fact, because no imagery instructions were given, it is not known that the subjects employed an imagery strategy even in the CPA.

Ernest and Paivio (1971a) have shown spatial ability to be equally and highly correlated with speed of evoking an image or a verbal associate to either concrete or abstract words. Because no information was given about the nature of, in particular, the verbal associates, any linking of this result with the present data is difficult. If, however, the verbal associates were a form of coding (their college student subjects were more likely to give abstract or paradigmatic associations, rather than sequential or syntagmatic ones), then Ernest and Paivio's results can be interpreted, as are the present results, in terms of coding as a form of simultaneous processing, which could have been indirectly measured by their tests of spatial ability.

The finding of an appropriate, that is, effective, means of coding is probably easier for the concrete words. In fact, because the APA mean is low, the successful coding of relatively few pairs might produce the observed relationship. The loading of both tests upon the speed factor would indicate that less complex mechanisms (perhaps simple recency effects from STM) are also operative in these tasks.

The significance of the present results is that, in contradiction to Paivio (1975, p. 161), abstract words can be integrated in memory in a way that is not necessarily sequential. The results suggest, rather, that the word pairs of both APA and CPA are integrated by means of a form of coding that involves simultaneous processing.

Relations with paradigmatic and syntagmatic paired associates

The hypothesis that simultaneous processing is the mechanism by which word pairs can be coded to facilitate paired associate recall is complicated by the factor analysis of the PPA and SPA tests with the simultaneous-successive battery. The loading of both PPA and SPA on successive processing (Table 25) is best explained by the nature of the word pairs that compose these lists.

The PPA and SPA lists were assembled by Denney and Ziobrowski (1972) to consist of word pairs that had high associative frequencies, unlike the previous paired associate lists, whose words (or numbers) had been chosen at random, producing supposedly negligible association values. If successive processing is that which deals with sequential associations, the loading of PPA and SPA upon this factor would seem to reflect the associative nature of these word pair lists.

While not testable in the present context, this hypothesis does suggest some testable predictions. In general, lists whose pairs have high association values should load more on successive than simultaneous processing. As a corollary, lists of relatively unassociated words could be made to load on successive, through repetition or overlearning, as long as the learning trials did not encourage hierarchical coding. A second consequence of this hypothesis would be that when hierarchical coding (even of lists with high association values) is encouraged, recall should load on simultaneous processing. Hierarchical coding can be facilitated through instructions (as Paivio encourages imagery), or through longer study periods of supraspan lists (as suggested by the PMA memory test results).

The present results do not clarify greatly those found when the syntagmatic and paradigmatic lists are each presented in random order and clustering is sought in free recall (Kirby, Jarman & Das, 1975). Those results (Table 2) suggested that paradigmatic clustering was related to simultaneous processing, and syntagmatic clustering negatively to successive processing. At this moment, all that can be said is that the changing of task characteristics can also change the type of processing associated with success in the task.

CHAPTER VII

OUTLINE OF AN INFORMATION PROCESSING MODEL OF ABILITIES

The hopes that Cronbach expressed in 1957 for a joining of the two disciplines of scientific psychology represent the spirit of the present study. Briefly, what is needed is a psychological model which describes cognitive processes (how the mind works) and individual differences (what the mind accomplishes).

The central focus of this study has been the model of simultaneous and successive processing, operationalized by Das on the basis of Luria's work with the brain-damaged. This model is attractive because it attempts to describe test performance in terms of two ways of integrating information, either as a unitary, quasi-spatial code, or as an ordered, temporal series of units. This is the aspect of the model that has been most exploited in the present study. The relations between the factors of the simultaneous-successive battery and other tests and factors have been discussed in processing terms. In fact, no other suitable description of the data was found.

It was shown that certain of the other tests and factors could be well described as a function of these processes. For instance, the implication that spatial ability is reliant upon simultaneous processing was confirmed. More surprising was the complex way in which the various memory tests (PMA, CPA, APA, PPA and SPA) related to both successive and simultaneous processing. Finally, the reasoning factor (perhaps representative of Gf) seemed to relate to the processing factors, mainly as a function of the task materials (the nonverbal test to simultaneous, the verbal one to successive). This last finding recalls Das' (1973a) results, which showed a verbal intelligence or school achievement factor to be orthogonal to simultaneous, successive and speed factors (this factor analysis is reported in Table 1 of the present report). The present results show inductive reasoning to be the PMA factor least well related to the processing factors. If, as will be suggested below, much of the active processing or transforming of information takes place at the short- and intermediate-term memory level, reasoning's independence from this processing indicates its reliance upon deeper factors. This would support Carroll's (1974) suggestion that individual differences in an inductive reasoning task are not so much a function of short- or intermediate-term memory (where much active coding takes place) as a function of the existence of appropriate hypotheses in long-term memory.

The present study was described at the outset as a few steps toward a theory of intelligence, a theory that would describe the cognitive processes and structures by means of which intelligent behavior is produced. Having completed the study, what now can be said about such a theory? First of all, the model of simultaneous and successive processing will be evaluated in light of the present results, following which an outline of a possible theory will be presented and discussed. Finally, the status of process theories and the problems associated with them will be examined.

Status of the Simultaneous-Successive Processing Model

The simultaneous-successive processing model is attractive for a number of reasons. Most importantly for the present study, it employs constructs which are easily relatable to those commonly used in cognitive experimental psychology. In that the terms of the model are cognitive and refer to processes which are inferred to actually be taking place, the model becomes a potential basis for a theory of intelligence. It is that theory of intelligence which is the real goal; such a theory would begin to indicate how intelligent behavior is produced and, conversely, how (and whether) unintelligent behavior can be improved. This theory would also integrate much of cognitive psychology.

An additional advantage to the simultaneous-successive model is its roots in Luria's neurophysiological research. While the connections between Luria's constructs and the battery developed by Das and his colleagues are yet to be validated, the possibility of such connections adds credibility to the model, in contrast to the doubt usually cast upon psychological constructs by neurophysiology. It must be pointed out that this validation would by no means be an easy task. Tests which discriminate well among the brain-damaged are frequently too simple to discriminate among even normal children. Perhaps more importantly, there is no simple way of knowing that the causes of a brain-damaged person's failure to perform a task are the same as those which prevent a normal person from completing the same task. Similarly, the aspects of the performance of a task which produce individual differences in that task in one group may not be the ones that produce individual differences in the same task in another group. If the connections between Luria's constructs and Das' operationalizations of those constructs are to be validated, the research design may well have to involve neuropsychological work with normal subjects; a possibility may be the recording of EEG in the areas identified by Luria during performance of the tasks in the simultaneous-successive battery.

For the purposes of the present study, it must be emphasized that these connections are not crucial. The invariance of this particular factor structure has been demonstrated now on many occasions, and the simultaneous and successive processing factors have been implicated in a number of studies involving low ability (Das, 1972; Jarman, 1975) or learning disabled children (Leong, 1974; Williams, 1976). In light of the robustness that this factor structure has demonstrated in the present study, it would seem that the factor structure has a reality of its own, even if that reality is not that of Luria's constructs. At the same time, it must be added that any attempt to characterize the nature of these factors produces constructs similar to Luria's, and this is strongly supported by the present study.

In comparing different models or different structures, as this study did, the most appealing goal at the outset is to reduce the existing theoretical complexity, to show that the factors or terms of all models are really the same as those of one model. As should be clear from the preceding research, however, that is not appropriate for the models studied. The present study stresses that the simultaneous and successive processing factors are not global categories of cognitive ability (as Jensen's Levels I and II can be seen to be), and are not new names for fluid intelligence, etc. Rather, they should be interpreted as ways in which the cognitive system processes information, as processes which can be involved at different levels of complexity and to different degrees in different tasks. Thus, what the simultaneous-successive model can offer is a way of interpreting other models, not a way of subsuming them. The interpretation of existing individual difference models of abilities in process-oriented terms (such as simultaneous and successive processing, but including others) will form the basis for a theory of intelligence that will describe how intelligent actions are produced and how individuals with cognitive difficulties might best be helped.

Outline of a Theory of Cognition and Intelligence

The theory or model will be presented in outline form. It is deemed premature to completely defend all of its propositions, nor will it be possible at present to describe the model as exhaustively as is desirable. The model is compatible with those of, for instance, Bower (1975), Hunt (1971, 1973) or Atkinson and Shiffrin (1968). The primary aim will be to demonstrate how the simultaneous-successive model, including those aspects presented by Luria (1966a, 1966b) but not examined in the present study, can be integrated with models of cognition from experimental psychology to describe intelligence or human abilities.

The model is described schematically in Figure 2. Structurally, the system has four components. The first is the sensory buffer, which can be conceived of as a very temporary (about 1/4 of a second) store

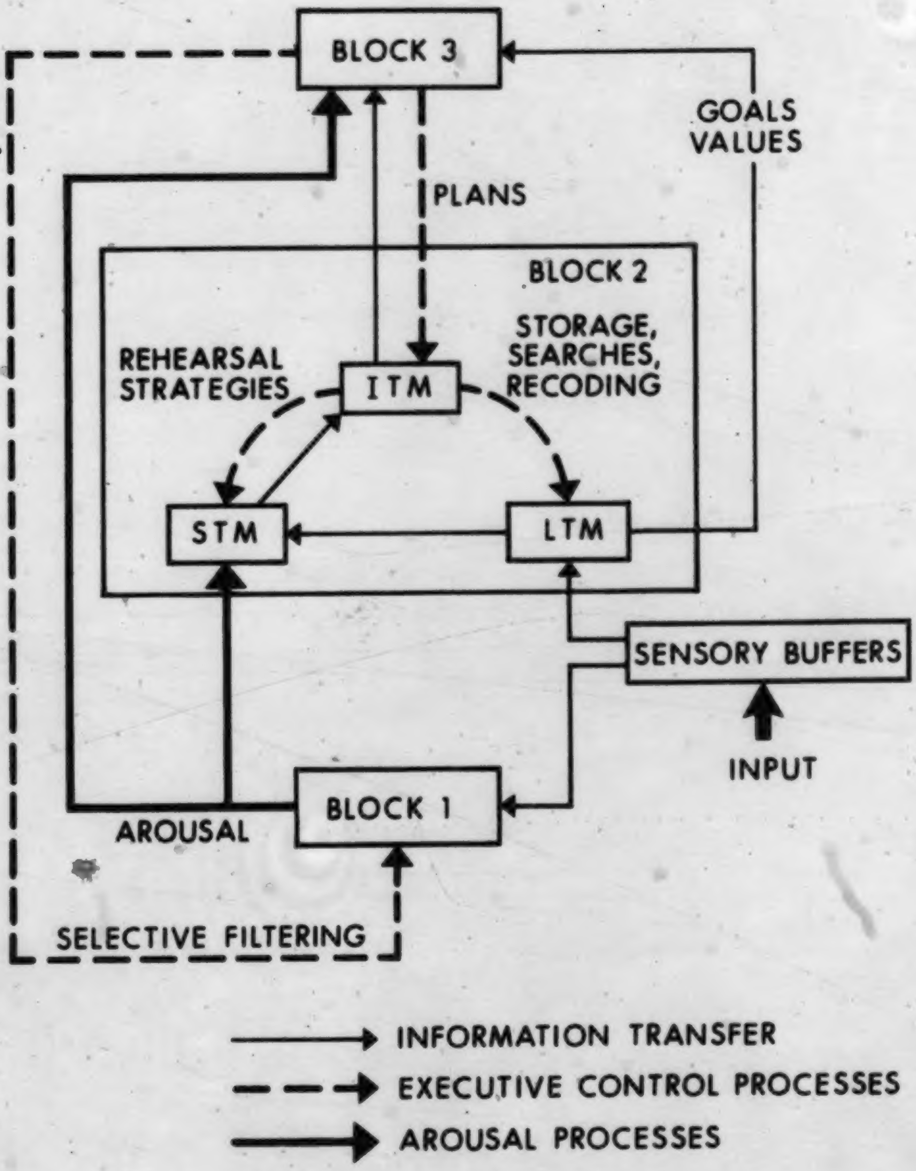
BLOCK 3
GOALS
VALUES
PLANS
BLOCK 2
STORAGE,
SEARCHES,
RECODING
REHEARSAL
STRATEGIES
ITM
STM
LTM
SENSORY BUFFERS
INPUT
BLOCK 1
AROUSAL
SELECTIVE FILTERING
INFORMATION TRANSFER
EXECUTIVE CONTROL PROCESSES
AROUSAL PROCESSES

Fig. 2. Schematic outline of a model of cognition and intelligence

for sensory stimulation which impinges upon the organism (e.g., Sperling, 1960). The other three components are Luria's three blocks of the brain, whose locations and functions have been described in Chapter II. The relationship of the sensory buffers to Luria's three blocks is not certain; the sensory buffer may in fact be a part of either block one or block two. To understand the functioning of the system, however, it is necessary to examine the more detailed structure of block two, as well as the ways in which information is transferred from unit to unit, and the control processes that determine which information is to be transferred and how.

Incoming information is briefly stored in the sensory buffers, over which little cognitive control is exercised. Because of the vast quantity of information stored in these buffers and the slowness with which this information can be transferred to a more lasting store, only a very small amount of the information is maintained for processing. Before much of this information is lost, however, aspects of it are transferred to block one, where it is evaluated on a number of relatively primitive criteria. These criteria do not involve meaning or complex characteristics of the stimuli, but rather relate to either simple stimulus characteristics (hotness, loudness) or simple learned stimulus patterns (hearing one's own name). The third block of the brain can in effect 're-set' this selective filtering mechanism for stimuli that are of importance to the current plan. When the criteria of block one are met, arousal messages are sent to the cortex (blocks two and three) to alert the cortex that something important is happening.

More complete information from the sensory buffers is sent to block two. This block consists of the three stores that Hunt (1971, 1973) listed--short-term memory (STM), intermediate-term memory (ITM or working memory), and long-term memory (LTM)--and the processes by which they are related. These memories, particularly STM and LTM, are best thought of as different kinds of excitation (or state) of the same neural representation, rather than being physically distinct in location. Incoming information is coded or chunked and LTM representations of these codes or chunks are excited and transferred to STM (or to an STM state). STM, it is well known, has a limited capacity (five or six chunks); when incoming information exceeds that limit, some is lost. Information stored in STM is available to ITM, which contains an up-to-date representation of the current plan (given to it by block three). Through ITM, and in accord with the current plan, information in STM is either subjected to repetitive rehearsal (Craik's [1973] maintenance rehearsal), or is recoded by ITM on the basis of information existent in LTM (Craik's [1973] elaborative or organizational rehearsal). ITM, then, is responsible, with block three, for comparing the input with what is desired by the current plan. If further actions are required to fulfill a plan, ITM initiates a response (not shown). STM functions largely through successive processing, which is also involved in maintenance rehearsal. Recoding performed by ITM generally makes use of simultaneous processing (hierarchical coding), but may also produce a temporally ordered sequence of hierarchical codes (successive processing). As Luria suggests, simultaneous and successive processing are ways in which block two receives, transforms and retains information of all levels of complexity.

ITM can also in effect interrogate LTM for stored information; this may require a search strategy, which would originate in block three. Through the processes of coding and recoding, block two in general, and ITM in particular, can have codes stored in LTM.

Little is at present known of LTM, but current theories (Anderson & Bower, 1973; Bower, 1975) describe it as a conceptual network of propositions (not necessarily verbal) about the world. Knowledge and skills, as well as long-term goals and values, are stored in LTM. The presence of these goals or values gives LTM an important role in the planning and motivation of behavior. The nature of the representation of information in LTM is also not known; information is probably not stored at any one point, but rather is distributed throughout the cortex. Because of the diverse information which is retained (spatial, psychomotor, olfactory, linguistic, etc.), it is unlikely that information is stored in, for instance, a verbal mode. Rather, as Pylyshyn (1973) has suggested, some abstract (perhaps propositional) form of cognitive representation must underlie the contents of LTM. Differences between left and right cerebral hemispheres may indicate that each is specialized for the processing or storing of different kinds of information.

Block three is the unit responsible for planning, control and decision making. On the basis of goals and values stored in LTM, and current information transferred to it by ITM, it constructs plans (Miller, Galanter & Pribram, 1960; Pribram, 1971) which are compared, in conjunction with ITM, with current input. On the basis of the discrepancy between plans and input, and as a function of more primitive arousal messages from block one (concerning, for instance, hunger, temperature, loudness of stimuli, etc.), block three decides upon a course of action, which is carried out in conjunction with ITM. Block three (the frontal lobes) is therefore involved in primary motivation or reinforcement (from block one) and in secondary or learned motivation or reinforcement (from LTM). Pribram (1971, pp. 337-345) has documented the complex interconnections of the frontal lobes and the limbic system, the latter consisting largely of subcortical block one structures and being important in motivation and learning.

How can this theory be related to intelligence? Three possible areas of relationship will be considered: structures, processes, and motivation. Implicit in cognitive models since Miller's (1956) "magical number" paper has been the idea of an STM capacity limit. He and others have shown this structure (or alternatively, state of excitation) to be limited to a small number of items. It would seem reasonable that other structures in the system will have capacity limits, either in terms of how much they can hold or in terms of how quickly information can be read in or out. While these structural limits are not normally associated with levels of intellectual performance, anything which acted to lower these limits (e.g., brain damage, high arousal) would impair performance. Additionally, while individual differences in these limits may not be highly related to individual differences in complex behavior, they are necessary stages in information processing. It is not known whether capacity deficits could be remediated.

The second area of relationships, processes, has been the central focus of the present study. The processing initiated in block two, including the initial chunking or coding and subsequent maintenance rehearsal and elaborative recoding, can be related to differences in intellectual performance (e.g., Belmont & Butterfield, 1971; Das, 1972; Ellis, 1970; Spitz, 1966). These processes can be seen to operate in essentially two ways: they create temporal series (successive processing) or hierarchical groupings (simultaneous processing). Two aspects of this unit are of interest in intellectual performance: is the optimal strategy (or process) being employed, and how good is the individual in employing this process? The first question relates to the quality of the information processing plan developed in block three. If suboptimal plans are generated, performance may be lower than that of which the organism is capable. To remediate poor performance, correct strategies can be taught (e.g., Krywaniuk, 1974), but may not generalize to new problems. The second question relates to quality of processing, in a sense, a capacity question. If for whatever reason (age, ability, background) the individual is not very competent with a particular kind of processing, then poor performance will result from using the 'optimal' strategy (poorly) or from using a suboptimal strategy. Little is known of the possibilities of improving quality of processing, as this has usually been confounded with improving the type of processing chosen.

While many more relationships with intellectual performance could be extracted from this model, the last to be considered concerns motivation. The third block of the brain is important not only for designing the particular plan to be executed, but also because it deals with plans, goals and values in general. In that it co-ordinates what motivates and satisfies the organism, block three will determine what the organism will attempt, in what directions its actions will be chanelled. The most competent processing will not produce intelligent behavior if misdirected. This implication of motivation in intelligent functioning supports the contention of some (e.g., Thorndike et al., 1921) that intelligence is more than abstract reasoning ability, which after all is just high quality processing. Block three also draws to our attention the limitations of any definition of intelligence: if one's group or culture does not define your goals (or values) as good, or intelligent, or of interest, then the best planning, best processing and best responding will be judged unintelligent. The model outlined briefly above does not define what intelligent action is; more fundamentally, it describes how that action is produced. Carroll's analysis (1974) and the present study have described how certain kinds of intelligent actions (the primary mental abilities) could be produced by a model such as that described above. The same model must be capable of producing a host of other actions which could be labelled intelligent (or desirable, etc.) by some other group.

The Problem of Process Models

It is appropriate that this last section should deal with the problems that arise from process-oriented models. The advantages of such a model over those that are merely empirically predictive (e.g., 'children who do well on verbal analogies tests also do better in school') have been described previously. While those models can adequately describe a static condition within a given population that is assumed to be homogeneous, they do not suggest means for altering undesirable states (poor performance), nor do they deal well with groups that are different. Many examples of this latter difficulty are provided by cross-cultural comparisons of predictors: when the same predictors do not function equally well in different groups, an empirical, predictive model can only search for new predictors in the new groups. Cognitive theories, which seek to describe how behavior and predictions actually come about, are more attractive for remedial purposes and for understanding how groups (and individuals) are different.

Cognitive or process-oriented theories are not without their problems. Because they often tend to be more vague in what they say, they also tend to be less easily proven wrong when they are. Essentially, two distinct problems can be seen with process-oriented theories. The first is that the nature of the terms used by these theories places them clearly in the realm of hypothetical constructs (MacCorquodale & Meehl, 1948), and brings in the difficulties of construct validation (Cronbach & Meehl, 1955). The second is that, through the judicious proliferation of processes, any results can be seen to support any particular theory. Both of these problems are accentuated when the processes in question are invoked post hoc.

Neither of these problems can ever be eliminated; they pose constant dangers which must be guarded against. In the present study, the processes to be employed were described as fully as possible before the data were examined. To raise the credibility of the processes invoked, all those employed were also ones well described in other areas of the psychological literature (e.g., rehearsal, chunking, recoding). Finally, when data give rise to process interpretations, those process interpretations should in turn give rise to further hypotheses to be tested in future research. Such hypotheses have been indicated in the present study.

In weighing the advantages and disadvantages of process interpretations, their advantages predominate. Those who propose process-oriented theories, however, must be aware of their potential for vagueness and irrefutability. One must concur with Cronbach and Meehl when they say:

> While we agree that psychological processes are elusive, we are sympathetic to attempts to formulate and clarify constructs which are evidenced by performance but distinct from it (Cronbach & Meehl, 1955, p. 286).

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